AN ABSTRACT OF THE THESIS OF

James D. Hastie for the degree of Doctor of Philosophy in Agricultural and Resource Economics presented on August 25, 1986.

Title: Economic Evaluation of Projects and Policies Affecting Anadromous Fish: A Simulation Approach

Abstract approved:
Bruce A. McCarl

Anadromous fish populations in the Pacific Northwest have undergone substantial change throughout the past century. Historical periods of over-harvest and the construction of numerous dams throughout the region have contributed to declines in the runs of naturally spawning stocks. Management efforts to rebuild fish populations have focussed on the restriction of harvest activities and the release of hatchery-reared salmon.

A microcomputer simulation model is developed to estimate the economic impacts of management alternatives. In it, fish are passed throughout a network of nodes, according to parameters governing mortality and harvest. These parameters, and the node structure itself, are provided to the model by a user-specified input file. As a result, the model affords flexibility in meeting the modeling needs of differing salmonid stocks.

The model's economic assessment capabilities are demonstrated through a case study of Rogue River spring chinook.

Results of this exercise include estimates for the impacts of dam construction, hatchery releases, and changes in ocean and river harvest policies on the social value derived from harvest activities. The research also examines the redistribution of economic benefits associated with these policies.

The impact of a recently constructed dam upon spring chinook fishermen is estimated at a loss of more than $10,600,000 over thirty years, given no hatchery supplementation. Current hatchery programs have mitigated the loss to fishermen, but whether they also offset their operating costs depends upon the particular harvest values employed. The value of providing an additional wild spawner to the basin is estimated to be roughly $300.

Examination of various harvest alternatives indicates that restrictions placed on the commercial ocean fishery would be more successful in increasing the present value of harvests than would similar restrictions in the sport fishery. An important factor in this outcome is the higher value attributed to sport catch by currently accepted methods of valuation.

Suggestions are made for improvements to the simulation model and the availability of information for use with it. Foremost among these is the need for improved specification of the marginal social value derived from salmon harvested in commercial and recreational fisheries.

Economic Evaluation of Projects and Policies Affecting Anadromous Fish: A Simulation Approach

by

James D. Hastie

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Doctor of Philosophy

Completed August 25, 1986

Commencement June 1987

APPROVED:

Professor of Agricultural and Resource Economics in charge of major

Head of department of Agricultural and Resource Economics

Dean of Graduate School

Date thesis is presented August 25, 1986

Typed by James D. Hastie for James D. Hastie

Acknowledgement

This dissertation is dedicated to my mother and late father, to whom I will always be gratefully indebted for their unending love and support.

I would especially like to thank Dr. Bruce McCarl for providing immeasurable assistance to the completion of this research, and for continuing to supervise it following his departure from OSU. Dr. Bruce Rettig played a valuable role as "major professor in residence" following Dr. McCarl's departure. Dr. John Edwards and Dr. Michael Martin are also extended appreciation for their service on my committee, the latter earning special praise for his entertaining and profitable seminars on turf grass management.

Stephen Cramer, James Lichatowich, and Barry McPherson of ODFW deserve thanks for their cooperation in providing data and judgment concerning Rogue River spring chinook.

Finally, thanks are given to the friends who helped me survive graduate school. Inside the zoo: Dr. Susan Garifo, Jan and Zazy Lewandrowski, Tom Frisbie, Tim Cross, Dr. Michael Hanrahan, Dr. Paul Turek, Peter West and Chris Scarzello, Sharon Kelly, Dr. Abdelbagi Subaei, and Kathy Carpenter. Members of the occasionally real world: Randy and Patty Paterson, Brian Hackenberger, Pat and Dr. Starr McMullen, Gary and Joni Cesario, Chris and Cindy Blatner, Earl Sutherland, and Dale Buckley.

TABLE OF CONTENTS PAGE

LIST OF FIGURES PAGE

LIST OF TABLES PAGE

Economic Evaluation of Projects and Policies Affecting Anadromous Fish: A Simulation Approach

CHAPTER 1 - INTRODUCTION

Anadromous fish populations of the Pacific Northwest have, throughout human history, played important economic and social roles in the region's well-being. In addition to the historical importance of salmonids within the religious and dietary customs of native Indian tribes, their abundance has facilitated the development of valuable commercial and sport fisheries.

As the human population of the region and markets for anadromous fish have grown, increasing demands have been placed on these fish and their migratory river environments. Increased awareness of the problems created by over-harvesting has led to stricter fishing regulations. In response, commercial fisherman have improved the efficiency of harvest activities through use of increasingly sophisticated technology.

Throughout this period of sustained harvesting pressure, the rivers which once provided an abundant and relatively free-flowing medium for migration to and from fresh-water spawning grounds have increasingly been obstructed by dams. These dams have facilitated a variety of beneficial uses including flood control, municipal water supply, hydroelectric generation of power, irrigated agriculture, transportation, and recreation.

While most of the dams allow up-stream migration through fish ladders, large areas of spawning habitat have, none-the-less, been rendered inaccessible by impassible dams. Even where passage is possible, the need for fish to locate the ladders and to adjust to changes in river flow and temperature resulting from water impoundment and removal has often had adverse impacts on migratory success.

Coincident with the construction of these dams, agricultural and forest practices--which can adversely affect habitat--have been intensified and substantial commercial fish harvests have continued. Throughout this period, there has been a reduction in the native runs of many species of salmonids. Recent interest in programs to mitigate fish losses has focussed attention on several fundamental issues.

The decline of numerous stocks of fish has led to questions concerning the kinds of efforts which could be undertaken to mitigate losses of fish. If societal value lost because of fish resource depletion is to be replaced in kind, what are the most efficient method(s) for doing so? To what extent have various "consumptive" uses of fish and habitat contributed to the decline in stocks? What is the value of this lost resource? How do ocean management alternatives differ in impact from those applied in-stream?

Additionally there is the matter of identifying, from among fish "user groups", the distributional consequences of policies and projects affecting salmonid survival and harvest opportunities. The importance of this issue is particularly apparent in situations where efforts to increase fish populations rely on restricting the harvesting abilities of one or more parties.

These issues have motivated the identification of five general objectives for this research; all of which relate to the estimation of economic impacts associated with policies or projects affecting salmonid survival.

The first objective is to estimate the change in fish-generated social value resulting from the emergence of a river obstruction, such as a dam. This involves identification of the effects that these obstructions have had on fish passage and spawning capabilities, and the resultant impact that this has had on the quantity and value of fish harvested.

The second objective is to assess the fish-related benefits and costs of potential or existing mitigation efforts. Of particular interest is the ability of hatchery operations to mitigate losses resulting from river obstruction. Also of interest is the marginal value of changes in the levels of hatchery releases.

The third objective is to estimate the impacts that changes in policy governing river and ocean harvest may have on the value of fish harvests. Of special interest is the question of whether lowering current harvest levels can effectively increase the present value of harvest over a long-run time frame.

The fourth objective is to assess the ways in which harvest policies and migration obstructions interact in affecting fish survival and societal value.

The fifth objective is to examine the distributional implications of various policy and program alternatives. Of particular interest are the trade-offs in benefits received by various harvesting groups within the framework of objective three.

The scope of the above-cited objectives is too great for a thesis project. For this reason, two operational objectives serve to focus the thesis research within the framework of the five objectives outlined above.

The first of these operational objectives is to develop an analytical tool capable of generating economic data relevant to the issues introduced above. The life-cycles of anadromous fish are complex, including linkages which can extend the impacts of current management decisions years into the future. A simulation model provides the opportunity to examine changes in this complex environment and the resultant economic effects.

The second operational objective is to demonstrate the ability of this tool to address questions representative of those inherent in the five general objectives. The Rogue River basin in southern Oregon serves as the setting for these case-study applications.

Chapter 2 provides a review of three items relevant to the exploration of the issues inherent in the general objectives. The first section documents changes which have occurred in anadromous fish runs in the Northwest. The second discusses the problems involved in modeling salmonid populations over time. And, the third section reviews the economic measures appropriate for use in the estimation of policy-induced changes in social welfare.

In response to the first operational objective, a computer model is developed which simulates the life cycle of salmon and economic values generated by their harvest. The structure of this model is presented in chapter 3. While the model is used in this thesis to simulate Rogue River spring chinook, chapter 3 also presents discussion on the capability of the model to address research issues for other salmonid populations.

Chapter 4 opens with a description of the Rogue River basin and its resident salmonid populations. A model setup which depicts the geography of the migratory route of the spring chinook is presented. This is followed by a complete exposition of the parameters used in the "baseline" study case. Finally, the performance of the model using these parameters is compared, where possible, with observed data for the basin's spring chinook population.

Chapter 5 presents the design and results of five applications of the model, in accordance with the second operational objective. Each application consists of several experiments with a common theme. These applications are intended to collectively address questions arising from the general objectives outlined above.

The first application focusses on changes created by the construction of a dam on the upper Rogue River and the extent to which a companion hatchery mitigates any losses in fish-generated value. The second application looks more specifically at the response of harvest values to changes in the level of output at the hatchery.

The third and fourth applications explore the effects of placing two different types of harvest restrictions on ocean and up-stream fishermen. In the final application, the combined effects of changing the rates for ocean harvest and passage at a dam are explored.

Chapter 6 summarizes the research activities reported in the thesis. Notable results from the experiments conducted are reviewed. Prospects for improvement and use of the model for future research are also addressed.

CHAPTER 2 - REVIEW OF SALMONID ABUNDANCE AND APPROPRIATE METHODOLOGY FOR ASSESSING VALUE

Historical Trends in Northwest Salmonid Runs

The magnitude and composition of salmonid runs and harvests in the Pacific Northwest have been altered greatly since the mid-1800's when white settlers first began to make use of this abundant resource. The Columbia River, once the location of the largest chinook run in the world, was a focal point of early fishing activity. It is used, here, to demonstrate the kinds of changes that have occurred in major salmon population throughout the Northwest.

Yearly harvest of chinook salmon on the Columbia, from the late 1880's to the 1920's, fluctuated between roughly 1 and 2 million fish (NWPPC), representing 20 and 40 million pounds (Van Hyning). By contrast, yearly harvest of <u>all</u> salmonids on the Columbia River since 1955 has not exceeded 1.1 million fish or 15 million pounds (NWPPC).

Though the decrease in river harvest correlates well with the development of numerous dams in the basin, the river harvest levels do not tell the complete story. Since World War II, the ocean commercial fishing industry has played an increasingly dominant role in salmonid harvest.

In recent years, up to 75 percent of some Columbia River chinook stocks harvested have been caught in commercial fisheries off the coast of Alaska and British Columbia (BPA). The development of these fisheries, in conjunction with greater restrictions on fishing in the Columbia (Van Hyning), has reduced the availability of fish for in-stream harvest.

Estimation of the contribution of Columbia River chinook to all commercial fisheries is complicated by the difficulties involved in identifying the origin of ocean-caught fish. Only where juveniles have been marked or tagged can identification be made, and this practice is necessarily restricted to small samples of the population.

If the catch-to-escapement ratio for tagged Bonneville upriver bright hatchery stock--about 2 to 1 (BPA, 1985)--is taken as representative of all chinook from the Columbia, then total catch may be crudely estimated using Bonneville Dam fish counts as a measure of escapement.

Using this measure, harvest would have ranged, over the past twenty five years, from roughly 500,000 to 1 million fish, with an average of about 700,000, or about 11 million pounds. These estimates are well below the river harvest levels for the 50-year period preceding the completion of Bonneville Dam in 1938. During this 50-year period, the number of chinook caught dropped below 1,000,000 only seven times, averaging over 1.2 million fish (NWPPC).

This reduction in the harvest contribution made by Columbia River chinook is also reflected in the poundage of all Pacific chinook harvested by U.S. commercial fishermen. While an average of 36 million pounds per year were harvested in the 1950's, this fell to 29 million pounds throughout the next two decades (NMFS).

Responsibility for the decline in chinook harvest must be shared by both the extensiveness of past fishing activity and the continued reduction in high-quality, accessible spawning habitat. Within the Columbia basin, an estimated 50 percent of the habitat once available for spawning has now been rendered inaccessible because of dam construction (ODFW, 1982). Dam construction has reduced available habitat in other Northwest river basins as well.

Furthermore, the spawning habitat which remains is subject to degradation caused, for example, by agricultural and timber practices (Huppert et al.) or by the slack water lying behind passable dams (Van Hyning).

Poon and Garcia have observed, however, that the loss of quality spawning habitat has not been the most important cause of population declines. Their 1982 survey of Western salmon-producing rivers found that nearly all of the major basins had significantly under-utilized spawning capacity. They attributed this condition, primarily, to the depletion wild stocks through over-harvesting.

In light of these habitat and harvest pressures, it is remarkable that the numbers of fish returning past Bonneville Dam are currently at levels as great as those immediately following the dam's construction for all species except summer chinook. Two major factors have contributed to the maintenance of escapement, or its restoration to, current levels.

The first of these is the regulation of commercial fishing activities. As mentioned, the commercial fishing season in the river has been shortened dramatically over the years. This affords returning fish a greater chance of successful up-stream migration after they reach the river. In addition, ocean commercial fisheries have been increasingly regulated with an eye toward the provision of desired escapement levels to spawning streams.

The second factor is the development of extensive hatchery operations throughout the basin--and the entire Pacific Northwest. One estimate places the contribution of hatchery fish--of all species--to west coast fisheries at about 20 percent (Stevens and Mattox). This contribution surpasses 50 percent for some chinook fisheries.

The growth of hatchery propagation activities, combined with the reductions of many naturally spawning stocks has, in turn, generated concern over the maintenance of adequate long-term genetic diversity in the salmonid populations of the Northwest (Walters and Cahoon).

In summary, then, native stocks of anadromous fish have been subjected to extensive harvesting and a reduction of spawning habitat over the last hundred years. As a result, the contribution of native salmonid stocks to Northwest fisheries has been reduced. In response to this condition, fish managers have sought to protect naturally spawning stocks through increased regulation of commercial fishing, while at the same time supplementing the supply of native fish through an extensive program of hatchery releases.

Some Difficulties in Evaluating Fish Management Alternatives

The goals of those charged with the management of anadromous fish species vary between agencies and jurisdictions. But, in general, there are at least two areas of broadly-defined similarity throughout. First, there is concern over providing adequate escapement, particularly for wild stocks, to insure the highest sustainable yield of fish possible. Second, there is an interest in attaining, within the context of other goals and mandates, the highest public net economic benefit possible.

Informed decision-making in this arena requires a tremendous amount of bio-physical research into the complex life-cycle of these fish. Life begins as the juvenile salmonids (fry) hatch from eggs laid in gravelly fresh-water streambeds. Following a period of growth, the juvenile smolts may migrate rather quickly to the ocean or may remain in fresh water for a number of years, depending upon the species and area of origin.

Once in the ocean, depending again upon the species and origin, they may remain one or several years before returning to the fresh-water spawning grounds where they were born. In general, returning spawners of the same species will be distributed among two or more prominent age classes. In most cases the fish die soon after spawning, but this is not always the case, particularly with steelhead (Larkin).

Throughout the migratory journey, which may extend thousands of miles, the fish are affected by diverse and changing environmental conditions--e.g. water characteristics, food availability, aquatic predation--in addition to assorted activities of man.

Research data concerning these factors is typically gathered for rather small chunks of, or specific relationships in, the overall life-cycle. As a result, managers have traditionally had to rely upon piecing together spawner-recruitment, escapement-catch and other estimated relationships in an effort to develop a more comprehensive picture of the outcomes of management alternatives. Needless to say, using this approach to predict the impact of current decisions on fish populations years into the future is cumbersome at best, and must necessarily exclude much of the variability present in the natural environment.

More recently computer models which simulate the dynamics of anadromous fish populations have become more accessible through the increased power of micro-computers. Interaction between researchers and fishery managers in British Columbia has successfully demonstrated the potential of micro-computer simulation projects to provide valuable information for policy and program development (Hilborn et al.).

But this and other "life-cycle" simulation efforts have focussed primarily on the estimation of biological accounting data, i.e. escapement, number of fish harvested, etc. In addition to these considerations, a modeling framework is needed which can provide information on how management decisions alter the benefits obtained by society from the fish resource.

Estimation of Appropriate Economic Measures

Projects and policies affecting anadromous fish often generate economic impacts which extend over a long period of time. In such circumstances, benefit-cost analysis is commonly used to assess the change in societal welfare resulting from the management action (Randall).

The meaningfulness of a benefit-cost assessment is dependent, in large part, upon two factors. The first is the accuracy with which resultant additions (or losses) of net economic value--benefits--to society are estimated. The second is the degree to which the discounting of future benefits and costs is consistent with the social rate of time preference.

The following discussion assumes a societal viewpoint for the analysis of welfare change. As a consequence, only the analysis of direct benefits created by an action is addressed. Secondary and induced benefits may be an important concern for management in some settings, but they are not examined here.

Direct benefits resulting from management of salmonid populations are derived from numerous consumptive and non-consumptive resource uses. These benefits may originate with commercial or recreational fish harvests, or the viewing of fish, and may include certain option or existence values attributable to stock maintenance. Within this thesis, however, only those benefits derived from the harvesting of fish will be examined.

On the commercial side, fishermen act as suppliers, providing one or more of several species of salmonids to processors who, in turn, produce various forms of product for public consumption. Government policies/projects may affect the willingness/ability of fishermen to supply fish in a variety of ways. The abundance of fish may be affected by a change in enhancement activities; regulations concerning acceptable gear may be altered; the length and location of allowed harvesting activities may be changed.

When management actions alter the effective commercial supply curve for a species in the market, the benefits may be observed in the changes of producer and consumer surplus values. The degree to which these measures provide an exact measure of welfare change is documented in Just, Hueth, and Schmitz.

Figure 2.1 illustrates a hypothetical market for commercially caught salmon. Curve D represents the market demand for a species of commercially caught salmon, while curve S shows the willingness of commercial fishermen to supply this species to the market, given an initial set of management policies.

Total societal surplus is shown by the triangular area OAB. Consumer surplus is shown by the area EAB and represents the difference between the willingness of the consumers in this market to pay for quantities of fish and the prevailing market price. Producer surplus can be seen in area OEB, which represents the difference between the market price and the variable costs of supplying quantities of fish to the market.

Assume, now, that the original configuration of management alternatives is altered in such a way as to shift the supply curve from S to S'. The resulting societal surplus is shown by

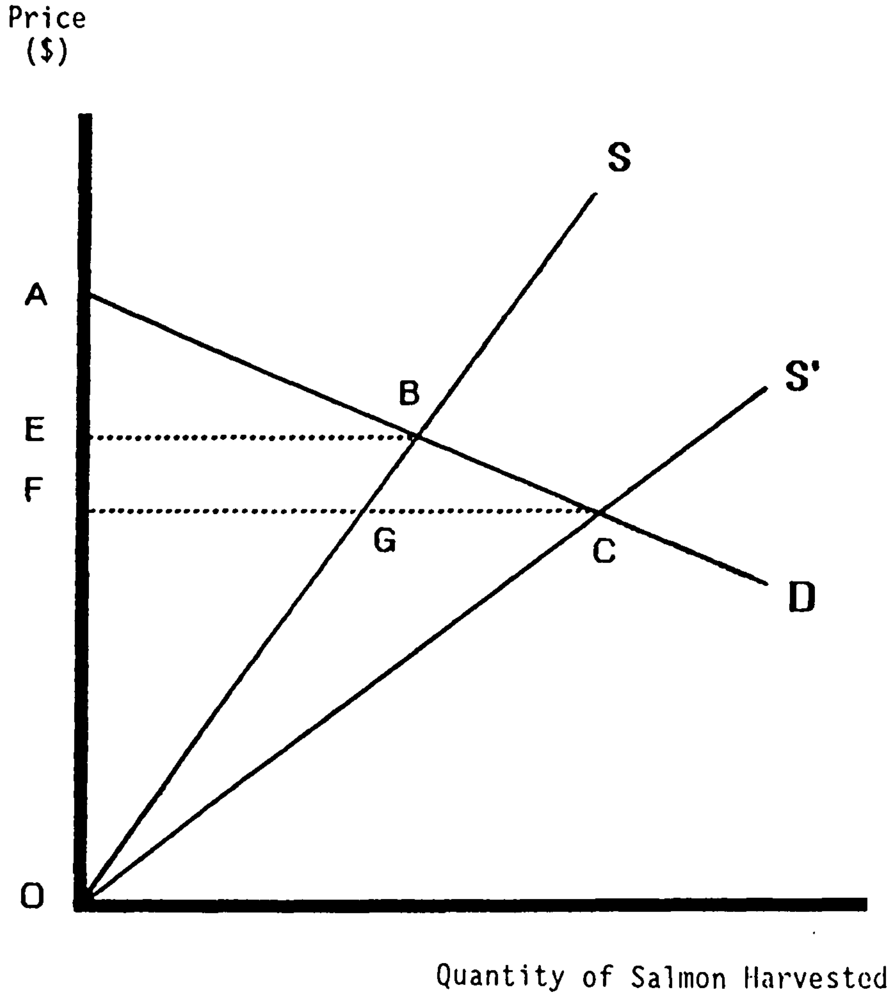

Figure 2.1 Producer and Consumer Surplus in a Hypothetical Commercial Salmon Market.

area OAC, with a total increase equal to area OBC. Consumers receive an outright gain by the amount FEBC. Producers lose the area FEBG but gain back area OBC.

Analysis of welfare changes in the recreational fishery is complicated by the absence of a well-defined market for acquiring the fishing experience. In contrast to the commercial setting, the fisherman is now, primarily, a consumer of this experience. The utility derived from the experience may be regarded as a function of the number of fish caught, the crowdedness of the fishing area, the aesthetic beauty of the area, the time and resources required to get to the site, as well as other factors. An individual's willingness to pay for the fishing experience is appropriately viewed as a function of these components and the individual's income. While this willingness to pay is not directly observable through transactions for the experience, it can be estimated using the widely accepted techniques of travel cost or contingent valuation (Randall).

These techniques provide the means for estimating demand curves for angler-days such as those shown in Figure 2.2. Curve D depicts the willingness of fishermen to pay for days of the angling experience. Implicit in the construction of this curve is the assumption that angling success--either in actual or expected terms--is being held constant.

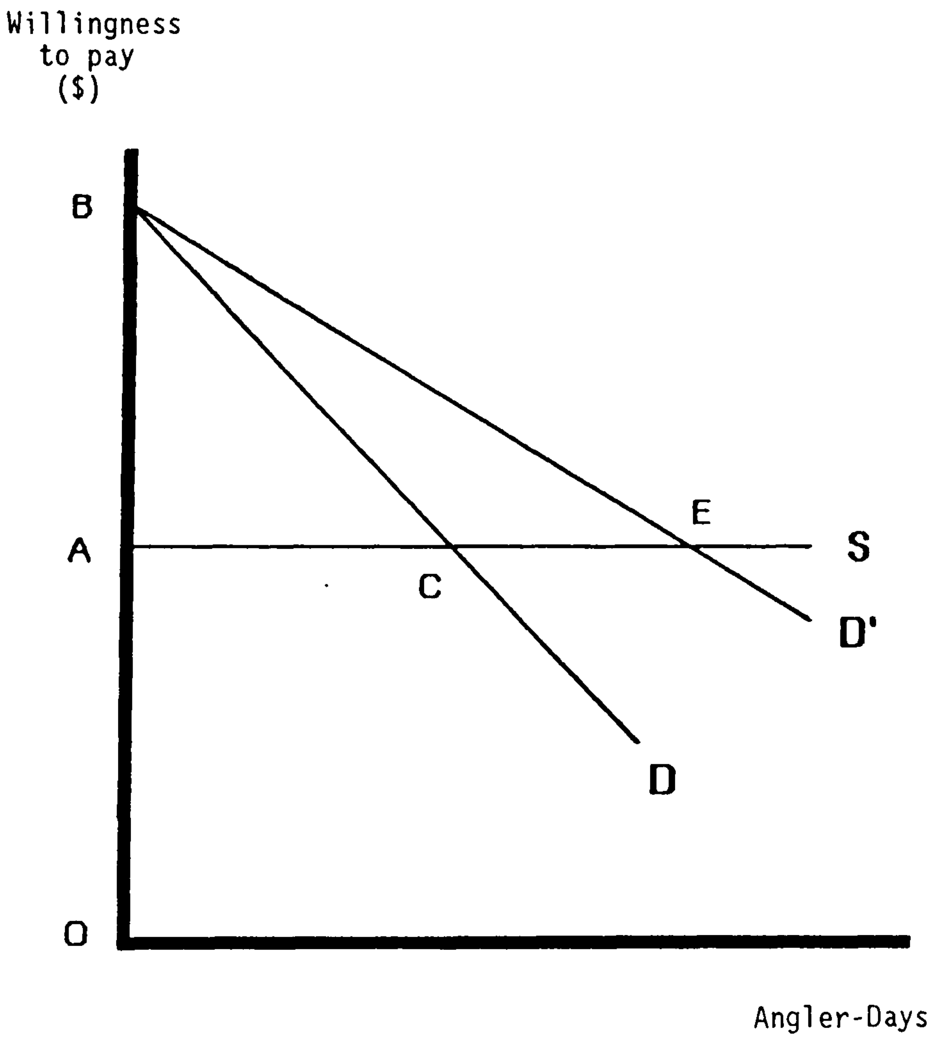

Figure 2.2 Consumer Surplus in a Hypothetical Non-Market Recreational Fishery.

Given that there is some representative price (A) associated with the acquisition of angler days, then the consumer surplus associated with demand curve D is the area ABC. This area is often referred to as willingness to pay above actual costs.

Now, assume that management undertakes measures to increase the number of fish available to this hypothetical sports fishery. Because the density of fish--and thus the expected catch rate--has increased, fishermen are now willing to "consume" more angler-days at a given cost. This change shifts the demand curve to D', adding the area CBD to the existing consumer surplus.

These methods provide the means for assessing the societal welfare change in the commercial and recreational fisheries resulting from management changes. When benefits occur over a number of years, as they are likely to do with anadromous fish populations, the need arises to convert these future benefits--and costs--into present equivalents. This requires that the future values be discounted by an appropriate factor. Among the considerations which determine a suitable discount rate are the social rate of time preference, the marginal rate of return to private investment, the opportunity cost of public investment, and the riskiness of returns from the project, relative to market alternatives (Mishan; Lind).

While examining the appropriate rate of discount for energy projects, Lind conducted an extensive analysis of after-tax rates of return for investments having varying degrees of risk. Based upon his findings for real rates of return for government bonds and a representative stock market portfolio, he concluded that the discount rate used should fall between 2.0 and 4.6 percent. Additionally, he argued that a rate of 4.6 percent should be used for

> "projects with the same risk as the market portfolio...Unless a strong argument can be made that the benefits and cost of a public investment or policy will not be highly correlated with the returns to the market portfolio."

It should be noted that this suggested rate of discount assumes that costs and benefits have been adjusted to reflect project/policy impact on private investment. In other words, it assumes that benefits have been reduced by the opportunity cost of expenditures for the subject project/policy.

From both public-policy and strictly economic viewpoints, it is desirable for managers of anadromous fish resources to possess information regarding the economic efficiency of alternatives (Huppert et al.). But models which can produce estimates of the societal benefits of decisions may also provide managers with important equity information regarding the degree to which different user groups will be economically affected.

The benefit-cost approach is based upon the concept of a potential Pareto-improvement. This means that the criterion places no special emphasis upon the surplus of any particular group. It only requires that those who gain as the result of an action be able to compensate those who lose--in accordance with the Kaldor-Hicks compensation criterion.

As a result, projects/policies with positive overall benefits may include significant redistributions of surplus. For this reason, the case-study analyses in Chapter 5 demonstrate how the simulation model may be used to identify user-group impacts, as well as overall efficiency outcomes.

CHAPTER 3 - THE STRUCTURE OF THE COMPUTER SIMULATION MODEL

The simulation model developed in this research evolved from the same conceptual base as the McCarl and Rettig model, but is designed to include more factors affecting fish survivability and value. It was also designed to provide a more flexible tool, wherein changes in the node structure could be accommodated without adjustments to the model itself. Thus the model is capable of being applied to a variety of problem situations. A listing of the Pascal source code for the model's program can be found in Appendix A.

In the model, the life cycle of migrating fish is represented by movement from one discrete node to another within an environmental system. Allowing the user to specify the inter-relationships between the nodes provides the ability for the model to be used in differing environmental conditions or river basins.

In order to facilitate use by a variety of different users, the model is implemented without a fixed internal structure relative to the migratory route of the fish. Virtually all information regarding the structure of the node system and the movement of fish within it is provided to the program by a companion input file. This allows for the testing of differing environmental/policy scenarios--as well as consideration of entirely different river basins--without the need for altering the program.

The model is configured to accept data for 25 different nodes and 6 different species. The number of times the program cycles through the nodes--with each complete cycle representing one year--is entered through the input file. Thus, the time horizon of analysis may be varied from one application to another. In addition, the program may be directed to repeatedly execute the simulation over the prescribed time horizon. If all of the parameters used in the model are constant, this feature serves no purpose. When various stochastic parameters are specified, however, it can be used to generate a probability distribution of results.

Description of the Model's Operation

For the sake of clarity, discussion of the model's stochastic features will follow description of the model in the context of static parameters. Figure 3.1 illustrates the simulated movement of fish through a simple node structure. The model begins with eggs, either in a spawning or hatchery setting, and converts them into fry to begin migration.

After leaving the initial node, the fish may be passed through a series of intermediate nodes, where some die and

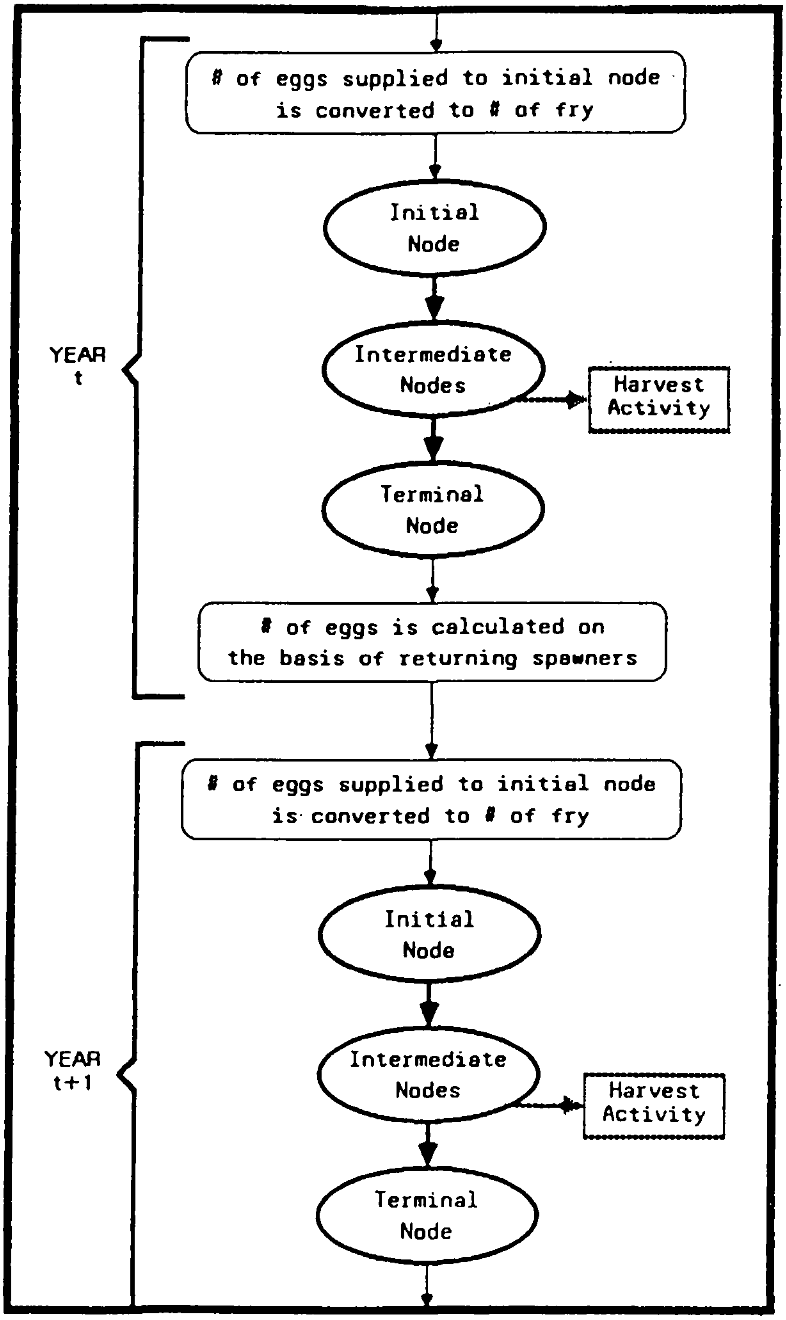

Figure 3.1 Flow Diagram of a Simple Model Structure.

others may be harvested. These movements are depicted in Figure 3.2. Some of these intermediate nodes may represent river migration, others may reflect ocean life. The fish that survive the intermediate nodes, reach the terminal node, producing eggs that will converted to fry for the next year of the model.

When a node is established via the input file, its relationship to other nodes in the system is defined, e.g. which node(s) fish enter from and which they leave to. Each node has a designated passage rate for each species. The passage rate equals the proportion of fish which "survive" a given node. The remaining proportion of fish (1 - passage rate) "die off" from the population at that point.

Before the "surviving" fish move on to the next node they are subjected to harvest according to rates specified in the input file. Up to seven different harvest parties may harvest fish within the node system. At each node, each of these parties may be assigned a proportion of the "surviving" fish of each species as its harvest.

The proportion of fish accruing to each harvest party is removed from the population and stored until the end of the cycle, at which time the entire catch of each party is valued. At this point, the proportion of "surviving" fish equal to (1 - harvest rate) is moved on to the next node. There is also provision for the setting of short-run harvest rates which are

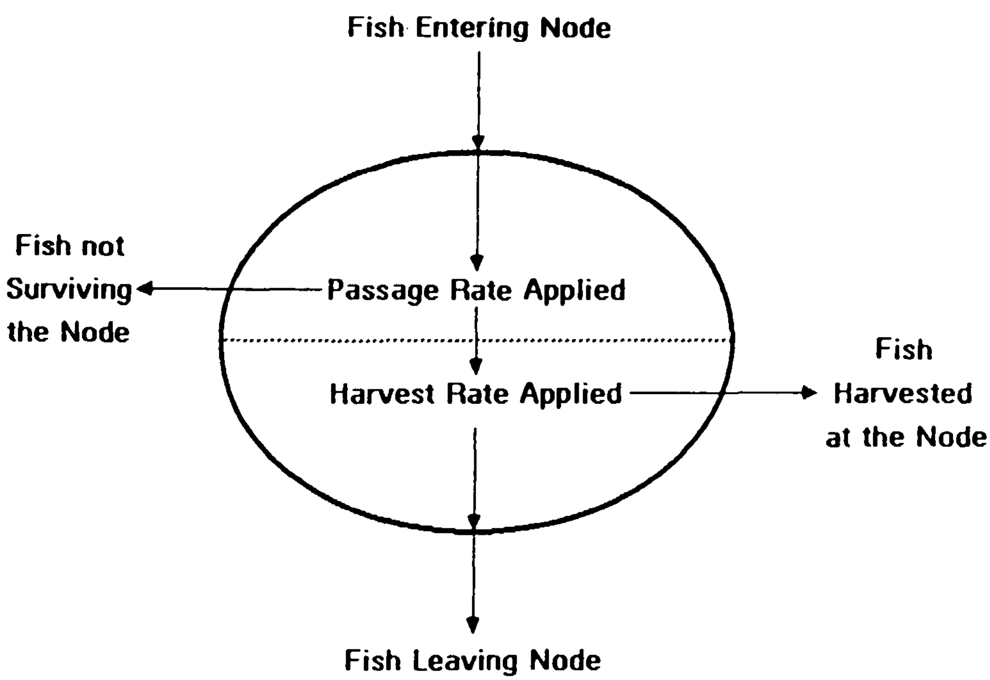

Figure 3.2 Movement of Fish Through an Intermediate Model Node.

effective only for a specified number of cycles--years--at the beginning of a run.

The processing of fish at any given node is, thus, a two-stage activity incorporating both passage and harvest considerations. This process is represented algebraically as:

$$2.1)\quad Q'_{s,n} = Q_{s,n} * PR_{s,n},$$

$$2.2)\quad Q_{s,n+1} = Q'_{s,n} * (1 - HR_{s,n}),$$

where Q represents the number of fish entering a node, Q' the number remaining after application of the passage rate, and s and n are indices for the species and node, respectively.

The statement that each cycle of the model represents one year is true in the strict sense only insofar as fish beginning at an initial node are one year younger than those starting at that node in the previous cycle. Since anadromous fish seldom return from the ocean within a single year, a lag may be specified such that fish moving from initial node to terminal node in one cycle of the model are not considered by the model to be one year old, but of an age equal to (1 + lag).

With most species of anadromous fish, adults from a particular brood do not all return to spawn in the same year. In order to account for this age diversity in returning fish, the model has the capability, for each species, to divert specified proportions of those fish reaching the sea into additional years of ocean life.

This is accomplished through the creation of modules for each year of delay desired. Fish diverted to these modules are stored there for the remainder of the cycle in which they entered. During the next cycle, fish stored in the module representing a one-year delay re-enter the main flow of the model and continue through to the terminal node(s). Fish in other delay modules are then advanced one module closer to rejoining the main flow.

Within each module, fish are stored according to their age. When they re-enter the main flow, the age composition--as a percentage--of each species is calculated and retained throughout the remainder of the cycle. In turn, this age information is utilized in both the calculation of species reproductive capabilities and the valuation of harvested fish.

After fish have been cycled through the entire model, those numbers reaching the terminal node(s) represent the spawners which will provide offspring for the corresponding initial node(s) of the model for the cycle (lag + 1) years away. All returning fish are assumed to die following spawning.

The number of eggs produced by each age class of the spawners of each species is calculated using four elements: 1) the number of fish, 2) the age-group percentage, 3) the age-group percentage of females, and 4) the age-group fecundity rates. The last two factors are provided as a composite number through the input file.

Maximum and minimum numbers of eggs surviving may be specified for each species. In addition to placing restraints on the spawning capacity of wild stocks, this feature may be used to fix hatchery output. Regarding this latter use, there is also the option of setting a different output level for a specified number of cycles at the beginning of each run. At the start of a cycle, the number of eggs of each species associated with the initial node(s) is converted into fry according to an equation of the following form:

$$2.3)\ \mathrm{Ln}(\ \mathrm{Eggs}_s) = [\ A_s + B_s * \mathrm{Ln}(\ \mathrm{Fry}_s)] * \mathrm{Ln}(\ C_s).$$

This conversion may be linear or logarithmic depending upon the values of A, B, and C specified in the input file. The potential for a logarithmic egg-to-fry survival equation allows the simulation of density-dependent relationships which may exist in the rearing habitat of wild stocks (Larkin and Hourston).

Economic values are generated within the model by valuing the results of harvesting activities. Each species is assigned a set of age-specific weights. Each harvest party is likewise assigned a set of age-specific prices for each species. At the conclusion of every model cycle, the value of the harvest for each party is then generated through a summation of values over the age groups of all species harvested by that party according to the following equation:

$$2.4)\ \text{Value}_p = \sum_{a=1}^{m} \sum_{s=1}^{n} (H_{s,a,p} * W_{s,a,p} * P_{s,a,p}),$$

where H, W, P represent number of fish harvested, fish weight, and fish price, respectively; s, a, and p are indices for species, age class, and harvest party; m is the number of age classes and n is the number of species. These yearly values are stored and at the conclusion of the run--for the specified number of years--they are discounted and summed to provide a net present value (NPV) of harvesting activities over the time-frame of the analysis.

Stochastic Parameter Possibilities

The preceding discussion has outlined the basic format of the model's operation in the context of static parameters. But the aquatic environment of anadromous fish is highly variable. Yearly, even seasonal, changes in river flow and temperature present new challenges to the migratory survival and propagation of fish stocks. In addition, variation in the ocean ecosystem not only affects survival rates, but also rates of growth and the amount of time spent in the ocean before returning to spawn. Consequently, the potential for incorporating this uncertainty is an important feature of the model.

Since passage and harvest rates are the principal governors of fish movement throughout the simulation, it is through these two components that most of the stochastic features are incorporated into the model. As with the types of information discussed above, the dimensions of parameter variability are provided to the model through the input file.

At any node, the passage rate for a species may be stochastically specified, with either a normal or uniform functional form. The mean and standard error of the parameter distribution must be provided for the former; lower and upper bounds for the latter. This feature can be used to reflect conditions where the variation in fish survival rates at nodes is either poorly correlated or of a significantly different magnitude.

There is also the possibility that substantial correlation will exist between the variations of survival rates at certain nodes. This condition is most likely to occur at nodes representing locations throughout the river portions of the migratory journey.

The model provides for designation of "river" nodes and the inclusion of distributions of values for proportionally modifying passage rates for nodes along the down-stream and up-stream migration of the fish. These distributions are user-specified and allow ten different values to be stored in an array for each direction of river migration for each species.

At the beginning of each leg of river travel, elements from the arrays are selected, using a truncated normal distribution--the mean and variance of which are user-specified--for generating integers from 1 to 10. As fish of a particular species are transported through all of the nodes representing one direction of river travel, the existing passage rates--whether static or randomly generated--are multiplied by the selected modifier, producing the actual passage rates for those nodes for that cycle of the model. Thus selection of a modifier equal to 1.0 would have no effect on the existing passage rates during that cycle.

While fluctuation in river conditions can have a dramatic influence on fish survival, so can changes in the marine environment. Of particular importance for both the growth and survival of young fish is the relative availability of food they encounter upon reaching the ocean. This is incorporated into the model through an array of marine-environmental factors. These factors, which also have a neutral effect at a value of 1.0, serve two functions.

First, the factors modify the age composition of the stocks. When ocean environmental conditions are favorable--i.e. when the factor is greater than one--the percentages of fish distributed to the ocean delay modules is adjusted so that a slightly higher percentage of fish return at an older age, and likely at a greater weight and reproductive capacity. The reverse is true when conditions are unfavorable. Second, these factors increase or decrease fish survival across age classes depending on whether the factor is greater than or less than 1, respectively.

The final area in which stochastic specification enters the model is in the specification of harvest rates. Even when harvest policy does not change, it can be expected that changes in fishing effort and environmental conditions will result in yearly variation in the percentage of available fish that are harvested by a given party. Therefore, at each node where harvesting takes place, the harvest rate for each party for each species may be specified according to normal or uniform distributional forms, as in the case of passage rates.

With the exposition of the stochastic components of the model, equations 2.1 and 2.2 may be revised to reflect the addition of these components. Using the same notation as before, the two-stage movement of fish through the nodes with stochastic parameters can be written as:

2.4) $Q'_{s,n} = Q_{s,n} * [(PR_{s,n}:D_{s,n}) * (RL_{y,d}:D_s)],$

2.5) $Q_{s,n+1} = Q'_{s,n} * [1 - (HR_{s,n}:D_{s,n})],$

where D designates a probability distribution, RL the river level passage rate modifier, and y and d are indices of the year and direction of river migration for the latter.

Additional Information Used by the Model

In addition to the parameters governing movement and harvest of fish within the model, initial conditions regarding the number of fish must be specified in the input file. The number of eggs for each species entering the initial node(s) needs to be identified for the first cycle of the model and for each subsequent cycle up to the number of lag years being used. When the ocean delay option is in use, the input file must also indicate the existing numbers of each species by age class that are located in each of the delay modules being used.

CHAPTER 4 - THE ROGUE RIVER BASIN:

Background and Parameter Design

The area selected for case application of the simulation model was the Rogue River basin, located in the southwestern corner of the state of Oregon. There were several reasons for selecting this basin. One of the more significant was the body of biological research which has accumulated for the Rogue over the past 10-15 years. Another was the relatively compact nature of the basin, which empties directly into the Pacific Ocean at Gold Beach. The only major tributary in the basin is the Applegate River, which joins the Rogue about 153 km. from the ocean.

Six dams have been constructed above this confluence, three on each river. Savage Rapids, Gold Ray, and Lost Creek Dams are located at the 174, 202, and 253 km. marks, respectively, along the mainstem of the Rogue. No fish migration is possible above Lost Creek Dam. Gold Ray Dam has the only permanent fish counting facilities in the basin.

Another reason for selecting the Rogue basin was the presence of economically significant runs of numerous species of anadromous fish, including native populations of spring and fall chinook, winter and summer steelhead, and coho. Of these, spring chinook were chosen for analysis on the basis of several factors.

First, chinook make up the majority of the basin's anadromous fish runs, followed in numbers by steelhead and coho (Cramer and McPherson). The steelhead life cycle, in which juvenile duration in fresh water is less predictable and adults do not necessarily die after spawning, is less consistent with the structure of the model than is the chinook life cycle.

Rogue basin spring chinook spawn almost exclusively above Gold Ray Dam on the mainstem of the Rogue. From a data standpoint, the importance of this behavior lies in the fish counting station at that dam and the record of adult fish passage there dating back to 1942. Fall chinook, on the other hand, spawn predominantly in the Applegate River and in sections of the Rogue below Gold Ray Dam, where there are no counting stations.

Finally, with the construction of Lost Creek Dam, a compensatory hatchery program was begun at Cole Rivers Hatchery--adjacent to the dam--whose releases have been predominantly spring chinook. These factors--biological and economic importance, data availability, and the ability to simulate actual hatchery and wild stocks of the same species--combined to favor examination of spring chinook.

Counts of returning spring chinook passing Gold Ray Dam have been conducted since 1942. Throughout this span of years, escapement has varied nearly five fold--from 12,270 in 1984 to 59,043 in 1969. It has not been uncommon for runs to vary by 150 to 200 percent from one year to the next. For instance, in the three years preceding the record high in 1969, escapement totals were 31,422 (1966), 14,693 (1967) and 22,066 (1968) [see appendix]. From 1977-1984, the hatchery component of this run has averaged about 4,900 fish. Over this same period, hatchery releases have averaged about 800,000 smolts.

The Node Structure Developed for Modeling Rogue River Spring Chinook

Because the river migration of the spring chinook is generally limited to the mainstem of the Rogue, the network constructed for this research is a relatively simple one containing 14 nodes and no branches. This network is depicted in Figure 4.1.

For the purposes of this research, wild and hatchery fish are modeled as if they were different species. This is done to facilitate the specification of different passage and harvest parameters for each stock.

With this arrangement, Node 1, the initial node, represents the spawning grounds below Lost Creek Dam for wild stocks and the Cole Rivers Hatchery for hatchery stocks. Some wild fish--normally less than 17 per cent--spawn in Big Butte Creek, which

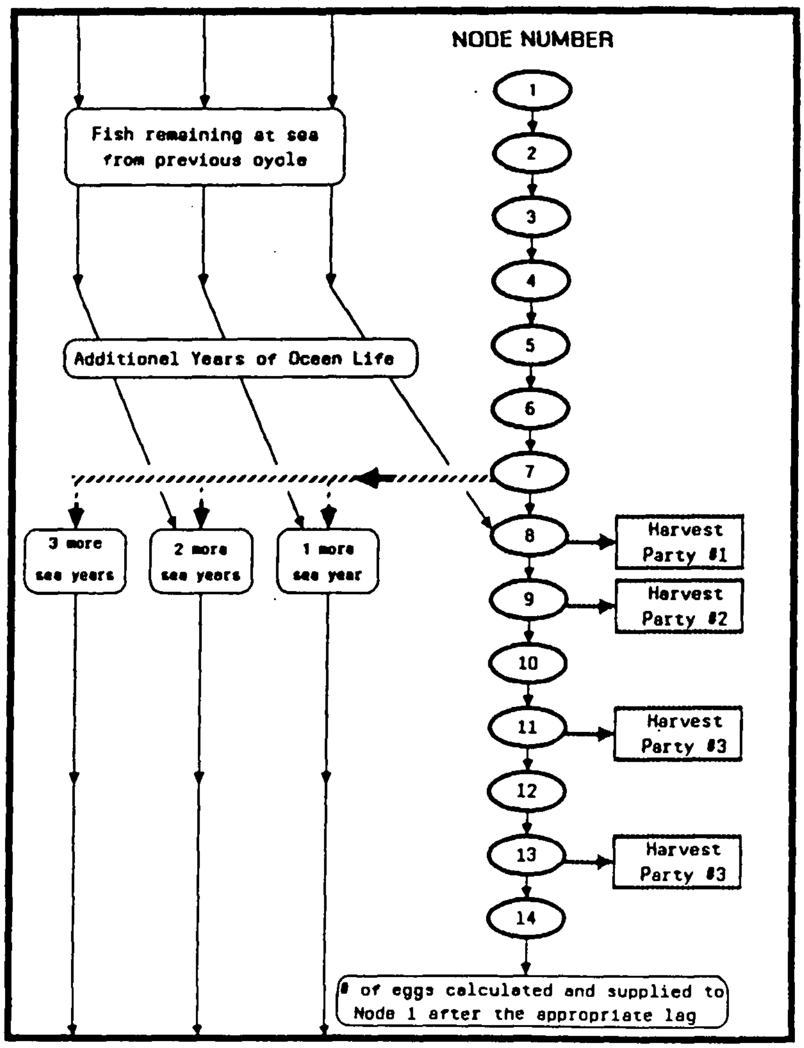

Figure 4.1 Flow Diagram of the Model for Rogue River Spring Chinook.

enters the Rogue at 251 km. As this percentage has dropped since the completion of the dam (Cramer and McPherson), all are modelled as if they spawned in the Rogue mainstem.

Node 2 represents downstream passage through Gold Ray Dam, while Node 3 continues through Savage Rapids Dam. Node 4 identifies the confluence of the Rogue and Applegate Rivers, and Node 5 the canyon area of the Rogue (70 km.). Node 6 represents the estuarine region at the mouth of the river, and by Node 7 the fish have reached the ocean. Node 7 is also designated as the node where selected proportions of fish are diverted into delay modules for additional ocean life.

Fish re-entering the model from the delay modules as well as those continuing directly from Node 7 enter ocean Node 8. From here, the fish return to the estuary at Node 9 and embark on their up-river journey, with Nodes 10 through 14 representing the same locations as Nodes 1 through 5 in reverse order. The numbers of wild and hatchery fish completing the cycle through Node 14 are then converted to eggs and saved for appropriate re-entry into the model at Node 1.

The harvesting of fish occurs at four nodes in the network. Commercial harvest of spring chinook only occurs in the ocean and is assigned at ocean Node 8. For the sake of simplicity, the commercial catch is attributed to a single party--harvest party 1--representing, primarily, fishermen in southern Oregon and northern California. Commercial fishermen operating farther north harvest very few of these fish because they migrate predominantly to the south.

Sport fishing is carried on at three nodes. Analysis of unpublished coded-wire tag data collected by ODFW indicated that recreational fishermen captured less than five percent of the Rogue spring chinook they caught in the ocean. This, in turn, represents less than one percent of the run entering the river. In light of this, sport fishing was assigned only to the river sections of the model. In the lower river, harvest party 2 is provided sport catch at Node 9. In the upper river, harvest party 3 brings in fish at both Nodes 11 and 13.

Estimation of Model Parameters

Even though there is an abundance of data for spring chinook, many aspects of the life cycle remain relatively unobserved. This results in the need for a considerable amount of manipulation of parameters at intermediate locations so that numbers of fish in the model are consistent with those at locations where observations are documented. In many cases, inferences regarding the behavior of wild fish have been drawn from the observations of tagged hatchery fish.

The primary objective in designing an input file for the Rogue, was the estimation of parameters for what will be referred to as the baseline case. This case is intended to reflect Rogue spring Chinook survival and harvest conditions during the period 1978-1983. Throughout this period Lost Creek Dam was operational and hatchery releases remained stable at roughly 800,000 smolts.

As a first step in the process of establishing passage--and where appropriate, harvest--rate parameters for each node, a spreadsheet was used to develop estimates of these rates. Using this tool, passage and harvest rates were adjusted throughout a similar 14-node system so that numbers of fish passing observation points and those harvested in various locations were consistent with the mean values of observed data. This was accomplished by harvesting the mean <u>number</u> of fish at each harvest location and then observing what rate was used to obtain that harvest after the remainder of the parameters had been adjusted to provide realistic escapement.

The rates from this first phase of estimation were then incorporated into the input file, run in conjunction with the various stochastic components of the model, and re-evaluated for consistency with observed passage and harvest numbers. Comparison of simulated and observed values is made following a discussion of the parameters used.

A listing of the input file used for the baseline case is provided in Appendix B, while the format of the input file is described in Appendix C. Table 4.1 shows the passage and harvest rate parameters--along with standard errors--which were finally chosen for simulating the baseline case.

The standard errors, where possible, were based on observed levels of variation. This information was, however, even less available than that for the rate means. As a result, most of the standard errors were assigned so that the coefficient of variation seemed reasonable given the predation or and other mortality factors at a particular location. Again, it is emphasized that, given the gaps in available data, there is no uniquely "right" set of parameters which represent this case.

The passage rates at Node 1 are based on unofficial estimates of predation and other mortality of newly hatched fish. But little information is available concerning juvenile mortality between the area above Gold Ray Dam and the ocean. The only official statistic recorded for outmigrating fish is the measure "smolt units", which is an index of the number of smolts trapped at Savage Rapids Dam. Because ODFW has converted this measure into a total number of outmigrating juveniles, it is of limited use in estimating an overall survival rate between Nodes 1 and 6.

As a result, passage rates at Nodes 2 through 5 were set so as to have individually small impacts on passage rates. Those at Node 6, however, were set so that the number of smolt units

Table 4.1 Passage and Harvest Rate Parameters from the Baseline Case.

NODE	LOCATION	PASSAGE RATE (S.E.) HATCHERY	PASSAGE RATE (S.E.) WILD	HARVEST RATE (S.E.) HATCHERY	HARVEST RATE (S.E.) WILD
Node 1	Hatchery/Spawning	0.70 (0.05)	0.73 (0.05)		
Node 2	Gold Ray Dam	0.95 (0.005)	0.95 (0.005)		
Node 3	Savage Rapids Dam	0.95 (0.005)	0.95 (0.005)		
Node 4	Confluence	0.98 (0.003)	0.98 (0.003)		
Node 5	Canyon	0.97 (0.003)	0.97 (0.003)		
Node 6	Estuary	0.55 (0.07)	0.55 (0.07)		
Node 7	Ocean	0.117 (0.01)	0.117 (0.01)		
Node 8	Ocean	1.0	1.0	0.33 (0.07)	0.33 (0.07)
Node 9	Estuary	0.76 (0.04)	0.76 (0.045)	0.0754 (0.003)	0.0735 (0.003)
Node 10	Canyon	0.94 (0.006)	0.95 (0.005)		
Node 11	Confluence	0.96 (0.005)	0.97 (0.004)	0.0271 (0.0025)	0.0309 (0.0028)
Node 12	Savage Rapids Dam	0.82 (0.04)	0.85 (0.035)		
Node 13	Gold Ray Dam	0.73 (0.06)	0.78 (0.055)	0.2210 (0.018)	0.2139 (0.019)
Node 14	Hatchery/Spawning	0.79 (0.05)	0.88 (0.03)		

would be within historical bounds, given an assumption of roughly 70 juveniles per smolt unit. The significantly lower passage rates at Node 6 also reflect increased mortality from predation and acclimation while first entering the marine environment.

Ocean passage and harvest rates were set, in large part, by working backwards from the end of the model. Figures from 1978-83 indicate that, on average, just under 60 percent of the hatchery fish observed at Gold Ray Dam survive to the hatchery. Passage and harvest rates for hatchery fish at Node 13 reflect this. The more favorable parameters for wild fish at that node are based on other research indicating greater survivability of wild stocks during migration (U.S. Army Corps of Engineers).

This assumption, that the wild stocks are marginally better able to survive the rigors of migration, is also incorporated into the passage rates at the other returning river nodes. These returning passage rates were set lower than their down-stream counterparts to represent the added difficulty of up-stream migration. Relative differences in the three sets of river harvesting rates reflect the proportions of wild and hatchery fish caught in each area (ODFW, 1983).

Having a good idea of what the river passage rates and the numbers of harvested fish should be, the ocean passage and harvest rates were set and iteratively adjusted along with the river harvest rates in order to increase the consistency between the simulated numbers of fish harvested and passing Gold Ray Dam and the actual data.

Fish surviving through Node 14 in the model are then converted into a number of viable eggs on the basis of two factors. The first is the relative age composition of the returning fish and the second a measure of the fecundity of each age class. The baseline case is specified with three periods of additional ocean life and a lag of two years for those fish passing directly through the model. Thus, returning fish will be members of one of four age classes--from two to five years old.

Ongoing and unpublished modeling efforts at ODFW provided the basis for much of the reproductive section of the model (Personal communication, Steven Cramer). Fish of each age class are assigned a "fecundity measure", calculated by multiplying the percentage of females in that age class by the average number of eggs produced by each female. Two and three year old fish are assumed to be inadequately developed to contribute to reproduction, and are assigned a "0" measure of fecundity.

Females comprise an average 51 percent of the four year old spawners with a mean production of 3600 eggs, for a fecundity measure of "1836". By comparison, 69 percent of the five year-olds, on average, are females, each capable of producing 3900 eggs, for a fecundity measure of "2691".

For wild fish, the carrying capacity of the spawning grounds is represented by a maximum egg limit of 29,000,000, with no minimum limit. For hatchery fish, the maximum and minimum limits are both set at 5,923,245 to provide for constant hatchery releases of 800,000 fry.

The age composition of a particular group of returning fish is, in turn, dependent upon three major factors: the percentage of fish which are specified to be routed through each of the ocean delay periods, the effects which the ocean environmental factors have on the base delay parameters during the execution of the model, and the relative size of the broods which contribute fish to Node 8 for return migration.

The percentage of fish diverted into various years of ocean life at Node 7 varies between the hatchery and wild stocks. For hatchery fish, the average proportions allocated to each age class--from two to five--are 0.08, 0.22, 0.58, and 0.12. Allocations to the same age classes for wild fish are 0.09, 0.22, 0.50, and 0.19. These proportions are based upon hatchery and other data compiled throughout the period 1977-1983 (Cramer and McPherson, and Evenson and Ewing).

During each year of the model's execution, these parameters are adjusted according to the ocean environmental factors, using the equations presented in Chapter 3. The components of the ocean environmental table used for both species are:

0.77 0.87 0.89 0.93 0.94 1.04 1.09 1.11 1.13 1.20.

These values were based rather loosely on an upwelling index obtained through ODFW (personal communication, Steven Cramer). For the period 1974-1983, this index ranged from 50 in 1978 to 205 in 1979, with a mean of 118 and standard error of 49.

The components of this table are selected, as mentioned in Chapter 3, using a truncated normal distribution. With the configuration of moments used, the central elements each have roughly a 13 percent chance of selection, which is reduced to about six percent for the outermost elements.The approach was used to allow the representation of occurrences having a likelihood of less than 10 percent, while maintaining the 10-unit limitation on the array of values.

At the beginning of each year, the number of eggs allocated to that year is converted into fry which will enter the model at Node 1. The equation used for this conversion is:

$$\mathrm{LN}(\ \mathrm{Fry}\ ) = 3.128528 + (\ 0.671 * \mathrm{LN}(\ \mathrm{eggs}\ )).$$

The functional form used as well as the value of the 0.671 coefficient were taken from the above-mentioned ODFW modelling work. The 3.128528 coefficient was chosen to provide a steady-state reproduction of fry, based on the mean number of spawners in the initial spreadsheet estimation phase. The simulated response of wild fry production to changes in egg abundance is depicted in Figure 4.2. The flat portion of this response curve reflects the modeled carrying capacity of the basin. Because of the lag incorporated into the baseline case, two years of egg values must be provided by the input file until the model is able to calculate egg production internally from returning spawners. Hatchery and wild stocks are provided 5,293,245 and 21,498,889 eggs, respectively, for each of these years. These egg amounts correspond to 800,000 and 1,900,000 fry entering Node 1.

The final factors which affect survival throughout the system of nodes are the river-wide passage rate modifiers. Slightly differing values are used for modifying the passage of hatchery and wild fish. Down-stream parameters for hatchery fish are:

0.94 0.96 0.97 0.98 1.00 1.00 1.02 1.03 1.03 1.04,

and for wild fish:

0.95 0.97 0.97 0.98 1.00 1.01 1.02 1.03 1.03 1.05.

Up-stream parameters for hatchery fish are:

0.94 0.95 0.96 0.96 0.97 1.00 1.01 1.02 1.03 1.04,

and for wild fish:

0.94 0.96 0.96 0.97 0.97 1.01 1.02 1.02 1.03 1.05.

These values are based, also rather loosely, upon the variation in spring stream flows below the canyon at

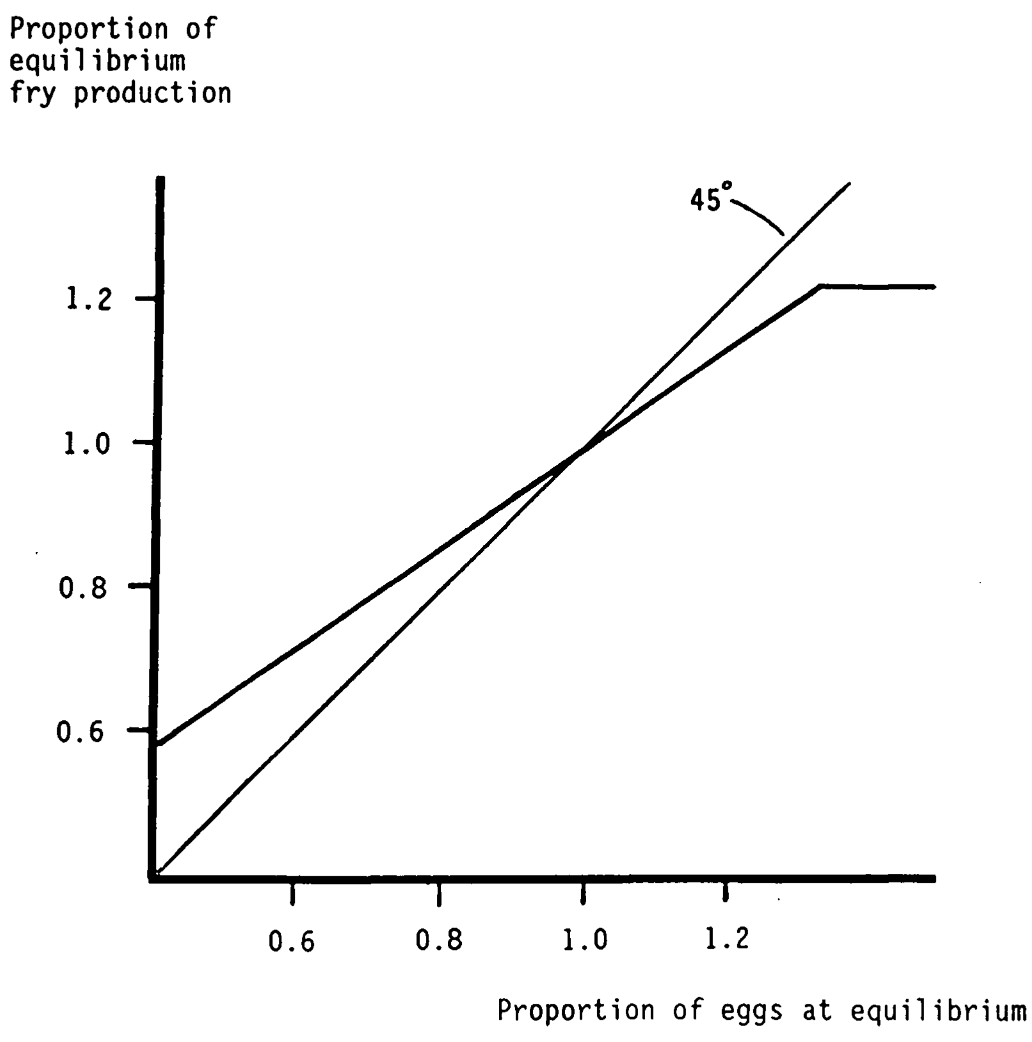

Figure 4.2 Fry Production-Egg Abundance Relation.

Agnes (48 km.). Between 1977 and 1983 flows ranged from 1,800 cfs to 10,000 cfs, with a mean of 5,880 cfs and a standard error of 3,190 (Personal communication, Steven Cramer). Since no estimates for a relationship between Rogue stream flow and migration survival could be located, it was assumed that average or slightly higher flows would result in the largest modifiers, followed by slightly below average, very high, and finally very low flows (U.S. Army Corps of Engineers).

The remaining parameters of the baseline case pertain to the determination of the value of harvested fish within the model. As described in Chapter 3, this is a two-fold process wherein, for each harvest party, the fish of each type are assigned a weight for each age class of fish. For each of these specified fish weights there is a corresponding price/value per pound. These parameters are listed in Table 4.2.

All of the fish weights used reflect state estimates of age-length (Cramer and McPherson) and length-weight (Lichatowich) relationships, with two exceptions. Ocean harvest weights, and prices, for age two fish are set at zero because less than one percent of the hatchery fish harvested are caught as two-year olds. The percentage of five-year old fish caught in the ocean is very small as well but instead of reducing their weight to zero, it was lowered to only 16.25 pounds for the

Table 4.2 Fish Weights and Values from the Baseline Case.

	POUNDS PER FISH						VALUE PER POUND (Dollars)	
	HATCHERY			WILD				
HARVEST PARTY	1	2	3	1	2	3	1	2/3
AGE CLASS								
2	0.00	2.6	2.6	0.00	2.6	2.6	0.00	7.33
3	6.75	6.8	6.8	6.75	6.7	6.7	2.00	7.33
4	13.20	15.7	15.7	13.20	15.5	15.5	2.50	7.33
5	16.25	22.0	22.0	16.25	21.0	21.0	2.75	7.33

purpose of producing accurate total poundage of the overall harvest.

The existing degree of model complexity and the unavailability of reliable demand estimates for this sub-market resulted in the use of very simplified measures of consumer and producer surplus for this demonstration.

In the commercial fishery, suppliers were assumed to face a perfectly elastic demand curve, because of the small potential impact of Rogue River spring chinook on Northwest chinook market prices. This eliminated any potential change in consumer surplus in the commercial market.

Producer surplus is estimated using a constant value per fish harvested. Determination of what this value should be is complicated by the likelihood that different kinds of management actions may result in different amounts of surplus--at the margin--per fish caught.

A small increase in hatchery releases, for example, might result in increased fish harvest with little or no additional harvesting cost or effort, particularly in the short run. In this case, the surplus derived from each additional fish caught could be approximated by the ex-vessel price.

Other decisions such as changes in the fishing season could lead to important adjustments in harvesting costs or restrictions limiting the supply of fish to an amount less than the market equilibrium level of harvest. In such cases the amount of additional surplus should be viewed as some fraction of ex-vessel price, within the point value framework.

There appears to be little consensus on what percentage of gross receipts should be used in estimating producer surplus values. Rettig and McCarl cite a number of studies indicating that the ratio of total variable costs to total receipts may vary from 5 percent to 100 percent for various commercial fishing operations.

They conclude that first year net benefits from a change in available salmon probably fall within the range of 50-100 percent of gross receipts. Citing limits to entry and excess capitalization in the industry, they also state that benefits in this range may reflect the potential for future benefits as well.

While Crutchfield et al. and Meyer have estimated benefits employing values of about 90 percent of gross receipts, Rettig and McCarl suggest the use of sensitivity analysis ranging from this value down to 50 percent. Throughout the applications of the model in this thesis, net benefits are estimated using a value equal to 90 percent of the ex-vessel price. In addition, one application includes calculations using a 50 percent value for purposes of comparison.

Ex-vessel prices for three size categories of chinook were reported for the 1984 season. Average price per pound for chinook over 11 pounds was $3.23; for those between 7 and 11 pounds it was $2.68; and for those under seven pounds it was $2.24 (Pacific Fishery Management Council). These prices were adjusted to reflect the weights of the fish in each age group of commercially harvested fish, and then reduced by 10 percent resulting in the values shown in Table 4.2.

The values used for fish caught in the river by recreational fishermen were based on an estimate of the marginal contribution of Oregon sport-caught salmon to consumer surplus (Brown and Shalloof). This value was derived from a pooled travel cost estimation of the demand for fishing trips to nine Oregon rivers.

Because the marginal value of $96 per fish suggested by Brown and Shalloof includes coho as well as chinook, it was increased to $115 to reflect the higher chinook value. This value was then converted to $7.33 per pound based on estimations of average fish weight. The value of $115 is comparable to those used by several Northwest agencies in their computation of project/policy impacts involving chinook salmon.

Use of a single value for estimating recreational surplus per fish possesses the same theoretical drawbacks as in the commercial sector. From a practical perspective, however, Brown and Shalloof were unable to reject the linear homogeneity of their overall demand function, leading to the conclusion that, at least on a statewide level, marginal and average values should not be too far apart. While this does not preclude the possibility of significant differences between marginal and average values in the context of a single river system, no reliable estimates have been made for these relationships.

Finally, a discount rate of 4.6 percent was chosen for calculating the present value of benefits from the harvesting activities. This value was selected on the basis of Lind's research and the fact that a thorough examination of the correlation between returns from fishing activities and those of a market portfolio is beyond the scope of this thesis.

It is noted, however, that various Northwest agencies, such as Bonneville Power Administration, employ a 3.0 percent rate of discount in benefit-cost analyses of salmon management alternatives (Dorratcaque). As an additional demonstration of the model's ability to facilitate examination of the sensitivity of conclusions to changes in parameters, some scenarios analyzed in chapter 5 are recalculated using discount rates lower than 4.6 percent.

Validation of the Model

Using these parameters for the baseline case, computer-generated fish counts and harvest information were compared to actual figures for the Rogue. Simulated fish counts for the node representing Gold Ray Dam averaged about 23,500 for 50 30-year model runs. The standard error for the simulated count was just under 7,000 fish.

The spring chinook count at Gold Ray Dam for the period 1980-84 averaged 21,800 with a standard error of 11,106. This period of post-dam impact on spawning grounds is, however, biased by the presence of two record low years in 1983-84. Lost Creek Dam may have played a role in these low runs, but it is generally acknowledged that unfavorable ocean environmental conditions were a principal influence.

Extending the period back another five years to 1975, the average increases to 25,400. Since this figure includes several years for which the dam did not affect spawning, it would appear that a figure closer to 24,000 would best represent the actual fish counts for the period modeled by the baseline case. Thus, the simulated fish count mean is within 5 percent of the actual. The simulated fish count standard error, however, is only about 35 percent away from the actual.

Over the last ten years, fish counts at Gold Ray Dam have ranged from 12,300 to 47,200. Simulated low and high counts for the baseline case were roughly 9,500 and 46,000, respectively.

Average ocean harvest of Rogue River spring chinook is about 37,700 fish, or about 374,000 pounds. Corresponding figures from the baseline case--for Harvest Party 1--are 34,400 fish and 350,000 pounds. While the actual figures imply an ocean harvest-escapement ratio of slightly more than 1.5, that for the simulated values is about 1.45.

In-stream harvest of spring chinook averages 9,700, approximately 148,000 pounds. Corresponding values from the baseline case--for Harvest Parties 2 and 3-- are roughly 11,000 fish and 146,200 pounds.

On the basis of this comparison between the simulated and actual values for harvest and escapement, the model and the baseline set of parameters were accepted for use in the experimentation reported in chapter 5.

CHAPTER 5 - APPLICATIONS AND RESULTS

In this chapter, the design and results of five analyses are presented. These applications were selected to demonstrate the model's capability to address the types of research issues identified in the five general objectives of this thesis.

All of the applications utilize data for spring chinook salmon originating in the Rogue River basin. All experiments are performed using 50 replications of the model over a 30-year time horizon. This number of replications was selected as a conservative sample size on the basis of a preliminary sample of model runs using procedures set forth by Cochrane.

Presentation of each application begins with a discussion of the general setting. This is followed by a delineation of the parameter changes used for each experiment with respect to the baseline case described in Chapter 4. The issues of interest in the application are identified, followed by analysis of the experimental results and a summary of findings.

Application A - Dam and Mitigation Impacts

The first application of the model is an ex-post evaluation of the impacts of the construction of Lost Creek Dam (km. 253), which cuts off upriver salmon migration, and associated hatchery mitigation activities. This application is designed to estimate the change in fish-generated value resulting from the elimination of spawning areas above the dam and to evaluate the degree to which post-construction levels of hatchery releases compensate for this loss. The sizing of hatchery output to achieve this goal is also addressed. Finally, all of the experiments are re-run with the surplus in the commercial harvest calculated as 50 percent of ex-vessel price instead of 90 percent.

Application A is partitioned into four model experiments. The first experiment (A.1) attempts to recreate the river environment and fish-generated value that existed before dam construction. This requires two major adjustments to the set of baseline parameters. The first of these is the elimination of the hatchery stock from the model. The second is alteration of the characteristics of wild spawning at Node 1 so as to reflect the larger spawning area and former size of the wild runs.

This alteration involves the modification of three parameters. First, initial egg values are increased from 21,498,889 to 31,682,573 to reflect the presence of about 7,000 additional spawning adults, on average. This adds approximately 900,000 smolts to the initial downstream migration at Node 1. The larger carrying capacity of the previous spawning range is represented through increasing the viable egg capacity from 29,000,000 to 45,000,000 , and through raising in the "central" value of the density-dependent egg-to-fry relation from 1,900,000 to 2,800,000.

Experiment A.2 estimates the value obtained after the dam is constructed, but without hatchery activity. In this case, the model uses all of the baseline parameters for the wild stock, but does not include any hatchery fish. Comparison of NPV estimates from A.1 and A.2 reveal the change in value due exclusively to the dam's presence. In A.3, addition of the current hatchery program to the analysis returns the parameters to the baseline case. Comparison of these results with those of A.1 and A.2 reveals the contribution of the current hatchery release program and the completeness of the mitigation effort.

In A.4, the level of hatchery releases is varied in order to identify a hatchery policy which most completely mitigates the change in value caused by the dam's construction. This release level is compared to that of the baseline case. Finally, in A.5, these same procedures are used, but variable hatchery operating costs are figured into the NPV.

The average NPV's for each of these scenarios, along with 30-year annuities are shown in Table 5.1. Standard errors of these values are shown in parentheses. These figures reflect a commercial value of 90 percent of ex-vessel price.

The impact of the dam, without hatchery compensation, is assessed by comparison of the first two scenarios. This

Table 5.1 Net Present Values for Application A--Commercial Values Set at 90 Percent of Ex-vessel Prices.

SCENARIO	TOTAL NPV ($) (s.e.)	DIFFERENCE FROM A.1	ANNUITY ($)	DIFFERENCE FROM A.1
A.1 No dam; No hatchery releases	34,573,767 (3,697,816)		2,147,577	
A.2 With dam; No hatchery releases	23,910,992 (2,498,414)	-10,662,775	1,485,250	-662,327
A.3-Baseline With dam; Release of 800,000	33,161,555 (2,494,594)	-1,412,212	2,059,856	-87,721
A.4 With dam; Release of 900,000	34,349,962 (2,523,543)	-223,805	2,133,675	-13,902
A.5 With dam; Release of 1,300,000; Hatchery cost included	34,583,064 (2,645,700)	9,297	2,148,154	577

reveals an estimated loss of $10,662,775 over the 30-year period, which corresponds to a discounted yearly value--annuity--of -$662,327. This loss is equal to about 2.9 standard errors using the values from scenario A.1. Despite the difference in magnitude of the two outcomes, the coefficient of variation for both scenarios is roughly the same, 10.7% and 10.4% respectively.

When the hatchery releases of 800,000 smolts are added for scenario A.3, NPV's return to within 4%--less than one standard error--of scenario A.1. This represents an annuity difference of approximately $88,000. A factor which may balance this remaining loss is the reduction in variability of returns. With the baseline set of parameters, the coefficient of variation drops to 7.5%. Depending upon the risk preferences of society this reduction might compensate for all or part of the lost average value.

While these model results indicate that placing greater reliance on hatchery stocks would be an effective means for reducing the degree of variation in returns, this inference should be moderated by the possibility that hatchery fish could, over the long run, be more susceptible to catastrophic depletion. Since the nature of such a possibility is not well-documented statistically, it has not been included in any of this testing and will not be explored further in the context of this thesis.

Scenario A.4 involved varying the level of hatchery releases by increments of 50,000 smolts in order to equalize the average NPV with that of scenario A.1. Setting the release at 900,000 resulted in the closest approximation of the original NPV, with a remaining difference of only $223,805. This suggests that the hatchery should release at least 900,000 smolts per year in order to fully mitigate the effects of the dam.

Figure 5.1 shows the cumulative distribution functions (CDF's) of the NPV results for each scenario of 50 runs. Comparison of the CDF of A.1 with those of A.3 and A.4 reveals that much of the larger variance in the NPV is attributable to observations that lie above the mean. This positive skewness in the distribution of returns from exclusively wild stocks is contrasted by the negative skewness in the returns of scenarios A.3 and A.4.

The above analysis has not included hatchery operating expenses in the calculation of NPV because the hatchery's primary purpose was to mitigate for fish lost because of Lost Creek Dam's construction. Experiment A.5 considered the level of hatchery output that would be needed to compensate for the

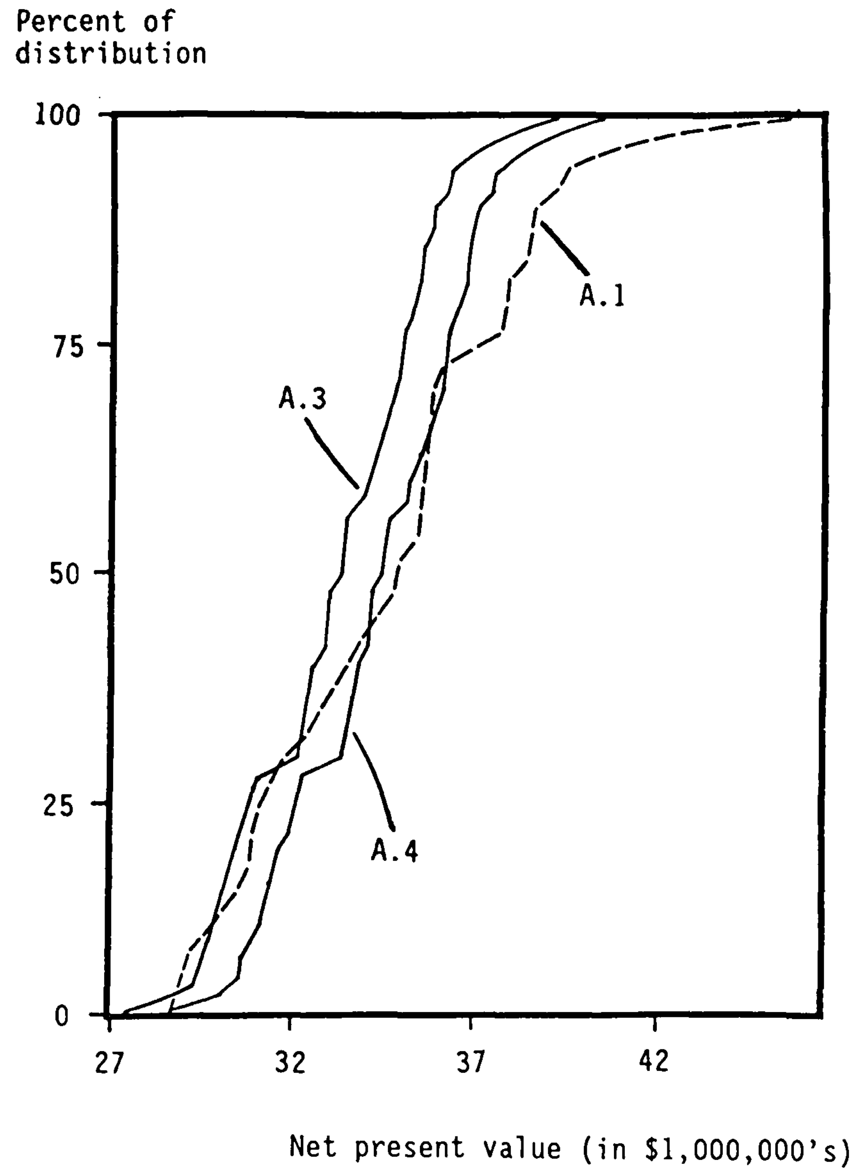

Figure 5.1 Cumulative Distribution Functions for the Benefits from Three Scenarios.

lost value if hatchery benefits are reduced by its operating costs.

The assumptions made with regard to hatchery operating costs are detailed in Application B. Using the same procedure as in A.4, it was found that hatchery releases would have to be set at 1,300,000 smolts in order to accomplish this goal. At this level, the annuity difference between A.5 and A.1 was less than $500.

It is interesting to note that yearly releases for 1985-86 have been approximately 1,600,000, well above the levels of hatchery output identified in A.4 or A.5 which would compensate for the original fish loss.

Table 5.2 shows results for the same set of scenarios, but with commercial value calculated as 50 percent of ex-vessel price. Accordingly, the values for commercially harvested 3-, 4-, and 5-year old fish were set at $1.11, $1.39, and $1.67, respectively.

Use of these lower values reduces the estimated loss attributable to the dam by about $1,800,000 to $8,803,637. All of the scenarios, with the exception of A.5, have values closer to that existing before the dam. As before, current levels of hatchery release would appear more than adequate to give back to fishermen the value lost because of the dam.

Table 5.2 Net Present Values for Application A--Commercial Values Set at 50 Percent of Ex-vessel Prices.

SCENARIO	TOTAL NPV ($) (s.e.)	DIFFERENCE FROM A.1	ANNUITY ($)	DIFFERENCE FROM A.1
A.1 No dam; No hatchery releases	27,177,926 (2,968,568)		1,688,178	
A.2 With dam; No hatchery releases	18,374,289 (1,964,270)	-8,803,637	1,141,333	-546,845
A.3-Baseline With dam; Release of 800,000	26,134,017 (2,025,073)	-1,043,909	1,623,335	-64,843
A.4 With dam; Release of 900,000	27,065,153 (2,044,867)	-112,773	1,681,173	-7,005
A.5 With dam; Release of 1,300,000; Hatchery cost included	22,725,240 (2,645,700)	-4,452,686	1,411,596	-276,582

The A.5 results are significantly lower--relative to the pre-dam situation--in the second run because the operating costs of the hatchery have remained the same while the value received from harvest has been discounted. This suggests that the choice of commercial harvest values may be very important in determining whether current hatchery policy has replaced all of the social value lost because of the dam.

In summary, the loss in welfare to the commercial and recreational fisheries resulting from the construction of Lost Creek Dam was estimated at $10,662,775 over a thirty year period. This loss was not totally mitigated by original hatchery releases of 800,000 smolts.

Recent increases in the level of hatchery output, however, appear to be more than adequate for replacing the lost value to fishermen. This conclusion does not seem to be extremely sensitive to the value attributed to commercially harvested fish. If the broader viewpoint is taken, however, that the hatchery should replace the lost value and cover its own operating costs by generating additional value, then the choice of values is an important consideration. If value is set at 90 percent of ex-vessel price, then costs appear to be covered at current release levels. This is not the case if value is lowered to 50 percent of ex-vessel price.

Application B - Contribution of Hatchery Releases

The second application focusses on the change in NPV resulting from adjustments in hatchery output. Experiment B.1 begins with the baseline parameters and then varies the number of fish released by one (B.1a) and five (B.1b) percent over all 30 years of the model. For experiments B.2a and B.2b, the same percentage changes are used but for only the first year of the model's execution. In addition to presentation of NPV changes, expenditure elasticities and benefit/cost ratios are calculated for each of the scenarios.

Application B also includes estimation of the change in value generated by additive--as opposed to percentage--changes in releases. Experiment B.3 increases hatchery output above the baseline case by an amount equal to the number of fry produced by a typical four-year old wild female. Given the initial population conditions of the model this represents about 214 fry. This change is implemented in experiment B.3 through an increase of 2,361 in the number of hatchery eggs, for a one-year period.

This result is used for comparison with the value calculated for one additional spawning four-year old wild female in B.4a. The same increase of 214 fry is obtained by a one-year increase of 3,609 in the initial supply of eggs for the wild stock. In experiment B.4b, the value of this same increase in the wild stock is evaluated using a discount rate of 0.03 instead of 0.046.

Table 5.3 presents the results from the experiments of application B. A one-percent increase in hatchery releases over the 30-year period produced an additional $83,768 of NPV over the baseline case. The increase of five percent for the same period resulted in a proportionally similar gain of $418,825 in NPV. Increasing hatchery releases by one and five percent for a single year resulted in additions of $4,884 and $24,419, respectively, to the NPV of the baseline case. This represents an average addition to present benefits of $0.61 per smolt released in the current year.

Variable hatchery operating costs associated with increased releases were estimated from unpublished Cole Rivers Hatchery budget data for fiscal years 1986 and 1987. While the cost and amount of food for rearing were available separately for spring chinook, their share of total expenditures for personnel and services was estimated using the percentage of the total food budget allocated for spring chinook. From these figures, a value of $1.62 per pound of fish released was obtained. Assuming an average of 7.5 fish/lb. for model hatchery releases (Evenson and Ewing), the variable cost for 800,000 smolts--the baseline case--was estimated to be $172,800 per year, or

Table 5.3 Net Present Values for Application B.

SCENARIO	TOTAL NPV ($)	DIFFERENCE FROM A.3	BENEFIT /COST RATIO	NPV/COST ELASTICITY FOR HATCHERY FISH NPV	NPV/COST ELASTICITY FOR ALL FISH NPV
8.1a 1% increase; 30 years	33,245,323	83,768	3.013	0.881	0.253
8.1b 5% increase; 30 years	33,580,380	418,825	3.011	0.881	0.253
8.2a 1% increase; 1 year	33,166,439	4,884	2.828	0.829	0.238
B.2b 1% increase; 1 year	33,185,975	24,420	2.826	0.826	0.237
8.3 Hatchery added spawner		131			
8.4a Wild added spawner		284			
8.4b Wild added spawner; 3% discount rate		319			

$2,781,910 for the 30-year period.

Because of the limited availability of cost data, variable cost was assumed to be a linear function of the poundage released. This implies an additional yearly cost of $1,728 for a one percent increase in releases, and $8,640 for a five percent increase. These figures represented the total additional cost for experiments B.2a and B.2b, respectively. They indicate a cost of $0.22 per smolt, for a NPV of $0.39 per smolt for one year of release. The additional cost for experiments B.1a and B.1b were $27,802 and $139,087, respectively, for thirty years of additional releases.

Two elasticities are shown in Table 5.3. The first is calculated as the percentage change in NPV derived only from hatchery fish divided by the percentage change in variable cost. The second is the percentage change in total NPV divided by the change in variable cost. The B.1 experiments--in which the output change is maintained for 30 years--have almost identical elasticities, which are in turn slightly higher than the values for the B.2--one-year--experiments. This indicates a slight proportional benefit to maintaining the changes over a longer period of time.

The benefit-cost ratios are well over 2.0 for all four experiments, and again the results are clustered by the length of time which the changes are held in place. Both of the 30-

year experiments show benefit-cost ratios of roughly 3.01, while those of the one-year tests are slightly lower at 2.83.

The results of experiment B.4a indicate that the NPV of one additional spawning four-year old wild female is approximately $284 using the 4.6 percent discount rate. Lowering the discount rate to 3.0 percent increases this value to $319, as shown for experiment B.4b.

By contrast, the release of an equivalent number of fry from the hatchery (B.3) produces less than half of this change, only $131. One reason why this figure is so much lower than that for an additional wild female is that the constant level of hatchery releases used in this analysis does not allow an initial increase in the size of the hatchery release to produce any inter-generational effects.

In summary, adjustment in the level of hatchery output in the model revealed a NPV of $0.39 per additional smolt released. Benefit-cost ratios for a variety of release scenarios were roughly 2.9. The elasticity of benefits from hatchery fish with respect to changes in hatchery expenditures averaged about 0.85. Finally, the value of an additional wild female was estimated at slightly below or above $300 depending on whether a 4.6 or 3.0 rate of discount was used.

Application C - The Effects of Harvest Rate Reductions

Application C is examines the changes in value resulting from short term modifications in upper river and ocean harvest rate parameters. The motivation for this application, as well as the next, springs from the potential for increasing future escapement, and presumably harvest opportunities, through a reduction in current harvest.

All parameter adjustments cited for these experiments are from those of the baseline case. In experiments C.1a and C.1b, baseline harvest rates at Gold Ray Dam (Node 13) for wild and hatchery fish are decreased by 30 and then 50 percent, respectively, for a one year period. C.2a and C.2b maintains the same modifications for a period of five years, long enough for offspring of fish affected in the first year to return as mature adults.

Experiments C.3a and C.3b repeat these procedures for harvest rates in the ocean (Node 8) for a one year period; C.4a and C.5a for five years. Finally, experiments C.5a and C.5b reduce harvest rates at both nodes by 15 and then 25 percent for one year; C.6a and C.6b for five years.

Values generated by these twelve scenarios and the baseline case are analyzed on the basis of several different factors. Total NPV accruing to all harvest parties is the first. But the distribution of NPV among the harvest parties is also addressed. Finally, assessment is made of the inter-generational distribution of returns generated by the different alternatives. This is achieved through the additional calculation of NPV for three separate base years throughout the time horizon.

Table 5.4 presents the overall NPV's generated by the baseline case and each of the 12 scenarios in this application. The difference between the NPV of each scenario and that of the baseline case is also shown. With the results segmented into three general groups on the basis of where the restrictions in harvest are applied, it is readily apparent that reducing harvest rates is only effective in increasing NPV when the restrictions are applied to ocean harvest.

Two reasons are offered for the contrasting impacts of such restrictions placed upon upstream and ocean harvests. First, since hatchery output is held constant, there is no "future" increase in the size of hatchery stock populations implied by current harvest reduction. As a result, the value of harvested hatchery fish in the C.1 and C.2 scenarios must necessarily be lower than in the baseline case. Where the restrictions are placed on ocean harvest, there remains an opportunity for increased current harvest of hatchery fish by subsequent parties.

Table 5.4 Net Present Values for Application C.

SCENARIO	TOTAL NPV ($)	DIFFERENCE FROM A.3	HARVEST RESTRICTION
C.1a	33,119,196	-42,359	Upriver 30% Reduction - 1 year
C.1b	33,082,694	-78,861	Upriver 50% Reduction - 1 year
C.2a	32,905,760	-255,795	Upriver 30% Reduction - 5 years
C.2b	32,692,123	-469,432	Upriver 50% Reduction - 5 years
C.3a	33,216,967	55,412	Ocean 30% Reduction - 1 year
C.3b	33,247,135	85,580	Ocean 50% Reduction - 1 year
C.4a	33,473,400	311,845	Ocean 30% Reduction - 5 years
C.4b	33,527,353	365,798	Ocean 50% Reduction - 5 years
C.5a	33,156,331	-5,224	Joint 15% Reduction - 1 year
C.5b	33,157,078	-4,477	Joint 25% Reduction - 1 year
C.6a	33,202,634	41,079	Joint 15% Reduction - 5 years
C.6b	33,119,323	-42,232	Joint 25% Reduction - 5 years

This sequential characteristic of the harvest activities is the second reason. When restrictions are placed on upstream fishermen, a period of years must pass before any regenerative economic benefit accrues to the action, while current values are reduced. When the restrictions are placed upon ocean fishermen, however, their loss sustained in the current year is, in some measure, offset by the increased current harvests of river fishermen. This effect is certainly accentuated by the greater value attributed to sport--rather than commercially--caught fish.

Table 5.5 shows the annuity difference in NPV between each scenario and the baseline case. Also presented are the annuity NPV differences for each harvest party and for the hatchery and wild stocks. The results in columns 2-4 illustrate the tradeoffs between harvest parties when the restrictions are applied. Not surprisingly, harvest parties which were not subject to restrictions in a given scenario always realized an increase in the value of harvest. On the other hand, parties whose harvest was reduced, even for only one year, consistently realized a reduction in the yearly value of their harvest over the 30-year period.

As expected, column 5 reveals a consistent pattern of decrease in the value contributed by hatchery fish as restrictions on any harvest party become more severe. The value

Table 5.5 Differences from Baseline Annuity Returns for Application C.

SCENARIO	OVERALL	BY HARVEST PARTIES			BY STOCK	
		1	2	3	HATCHERY	WILD
C.1a	-2,631	3,387	1,769	-7,788	-2,672	39
C.1b	-4,898	5,383	2,812	-13,095	-4,401	-498
C.2a	-15,889	14,615	7,536	-38,041	-12,564	-3,325
C.2b	-29,159	23,068	11,899	-64,127	-20,750	-8,409
C.3a	3,442	-11,943	7,217	8,167	-2,999	6,441
C.3b	5,316	-19,980	11,860	13,435	-4,589	9,905
C.4a	19,370	-53,542	34,014	38,897	-11,216	30,586
C.4b	22,721	-94,465	54,729	62,457	-18,438	41,160
C.5a	-324	-4,519	4,471	-277	-3,317	2,993
C.5b	-278	-7,100	7,524	-702	-5,187	4,909
C.6a	2,552	-17,931	21,374	-893	-12,680	15,232
C.6b	-2,623	-32,681	34,604	-4,548	-21,222	18,599

obtained from wild fish showed just the opposite pattern in the last eight scenarios, increasing as controls became more restrictive. Only when controls were applied exclusively to the upstream fishery did the value of wild fish not respond in a positive manner.

In summary, short-run reductions in the ocean harvest rate resulted in NPV increases, while the opposite was true for reductions in the upper-river harvest rates. In addition, the imposition of these blanket reductions tended to redistribute benefits, rather significantly, away from the parties whose harvest was reduced.

Application D - The Effects of Minimum Passage Restrictions on Harvest Rates

Application D also addresses the issue of short term harvest restrictions versus long-run value. For this application, however, the mechanism for reducing catch is not the harvest rate parameter but the minimum passage requirement. Using this feature, the baseline harvest rate is maintained unless so doing would prevent the minimum passage requirement from being met. Under the later conditions, the minimum passage level is preserved, where possible, through reduction in the harvest percentage, down to a zero harvest rate if necessary.

For this application, mean values of fish survival following harvest at Gold Ray Dam (Node 13) and at the representative point of ocean harvest (Node 8) are calculated for the baseline case. For experiments D.1a and D.1b, minimum passage numbers are set at 95 and 105 percent, respectively, of the mean number of fish surviving after harvest at Node 13. These restrictions are held in place for the first year of the model. Experiments D.2a and D.2b extend these restrictions throughout the first five years of the model.

As in application three, experiments D.3a, D.3b, D.4a, and D.4b apply the same pattern of restrictions to Node 8--and its mean survival numbers-- for one and five years respectively. For D.5a, D.5b, D.6a, and D.6b, minimum passage requirements are set for each node at 85 and 95 percent of the appropriate mean and maintained for one and five years respectively. As in the previous application, analysis is made of the total, distributional, and inter-generational NPV's arising from these scenarios.

The results from these 12 scenarios are summarized in tables 5.6 and 5.7. As seen in application C, the imposition of harvest restrictions on the upstream harvest party did not increase the NPV of the spring chinook runs. One important difference in these outcomes of the first four scenarios lies in the change in the wild stock NPV resulting from the

Table 5.6 Net Present Values for Application D.

SCENARIO	TOTAL NPV ($)	DIFFERENCE FROM A.3	MINIMUM PASSAGE STANDARD FOR HARVEST RESTRICTIONS
D.1a	33,148,930	-12,625	95% of Upriver Mean - 1 year
D.1b	33,137,775	-23,780	105% of Upriver Mean - 1 year
D.2a	33,114,941	-46,614	95% of Upriver Mean - 5 years
D.2b	33,044,768	-116,787	105% of Upriver Mean - 5 years
D.3a	33,195,692	34,137	95% of Ocean Mean - 1 year
D.3b	33,241,015	79,460	105% of Ocean Mean - 1 year
D.4a	33,367,847	206,292	95% of Ocean Mean - 5 years
D.4b	33,535,323	373,768	105% of Ocean Mean - 5 years
D.5a	33,162,368	813	85% of Both Means - 1 year
D.5b	33,179,722	18,167	95% of Both Means - 1 year
D.6a	33,224,063	62,508	85% of Both Means - 5 years
D.6b	33,294,251	132,696	95% of Both Means - 5 years

Table 5.7 Differences from Baseline Annuity Returns for Application D.

SCENARIO	OVERALL	BY HARVEST PARTIES			BY STOCK	
		1	2	3	HATCHERY	WILD
D.1a	-784	3,821	2,246	-6,552	-1,931	1,147
D.1b	-1,477	5,545	2,850	-9,873	-2,971	1,494
D.2a	-2,895	13,441	6,790	-23,127	-7,196	4,301
D.2b	-7,254	20,624	10,497	-38,349	-11,887	4,633
D.3a	2,120	-1,928	1,888	2,160	-128	2,248
D.3b	4,936	-5,534	4,897	5,571	-488	5,424
D.4a	12,814	-9,746	10,410	12,150	-781	13,595
D.4b	23,217	-23,738	21,759	25,195	-2,343	25,560
D.5a	51	1,614	1,163	-2,727	-960	1,011
D.5b	1,128	1,132	3,441	-3,446	-2,081	3,209
D.6a	3,883	4,122	6,313	-6,554	-3,511	7,394
D.6b	8,243	695	14,794	-7,247	-7,444	15,687

restrictions. Instead of lowering this value, as in the previous application, the wild stocks yielded an increased value when harvest was restricted only in years where it was necessary to preserve minimum passage numbers.

Two conclusions may be drawn from this. First, if harvest restrictions are to be applied only to the upstream fishery, their implementation should be based upon the magnitude of the fish runs. Second, such restrictions should be accompanied by an increase in hatchery releases if the loss in value from this stock is to be offset.

The greatest gains from imposing the minimum passage harvest restrictions were seen, as before, when they were applied solely to the ocean fishery. It is important to note, though, that this type of restriction created much less variability in the values accruing to the various harvest parties than did the blanket restriction on harvest percentage used in application three.

Comparison of the results for scenarios C.4b and D.4b illustrates this point. Both sets of restrictions increase the total yearly value by approximately $23,000. In C.4b, ocean harvesters lose over $94,000 a year while each of the other parties gains in excess of $54,000 a year. In D.4b, on the other hand, ocean harvesters lose only about $23,000 and the gains to each of the other groups are of roughly the same amount.

If minimizing the distributional impacts of such attempts to increase NPV is viewed as an important policy goal, then it is desirable for the implementation of ocean harvest restrictions to be tied as closely as possible to the abundance of fish. In the real world, determining marine abundance of chinook salmon originating from a particular basin is problematic at best. Still, these results provide some incentive for attempting to improve the accuracy of techniques for estimating the size of returning chinook runs before they are subjected to ocean harvest.

Implementation of the minimum passage harvest restrictions jointly in the ocean and upstream fisheries--the last four scenarios--produces moderately improved impacts on NPV over the comparable scenarios in application three. Here, while the upstream fishery's losses are increased slightly, the previous losses of ocean harvesters are converted to gains resulting in consistently positive changes in NPV over the range of restrictions tested.

In addition to distribution of NPV between harvest parties, the distribution of returns over time may also be an important consideration. In order to illustrate how the policies represented in Applications C and D affect the timing of harvest-value generation, NPV's were calculated over three ten-year time horizons--within the 30-year run of the model--for four of the scenarios.

Table 5.8 shows the percentage change in "decade" NPV from that of the baseline case for each of these scenarios. While all four show greater values in the last two decades than the baseline case, the largest increases--at least two percent in all cases--are seen in the second ten-year period of the model runs. This is not surprising, as the harvest restrictions for each of these scenarios are sustained for five years, fully half of the initial accounting period. By the third decade of the simulation, all but one of the scenarios returns to within one percent of the baseline values.

It is particularly interesting to compare the time-paths of the values for C.4b and D.4b, since these two scenarios produced roughly the same change in total NPV. For both scenarios, the only harvest party values which are below those of the baseline case are those for the ocean harvest in the first ten years. And in the case of D.4b the loss is only about 6.5 percent. But for C.4b, the loss to ocean harvesters for the first ten years is a substantial 22.5 percent.

The regenerative contribution of the 50 percent cutback in ocean catch for the first five years in C.4b can be seen in the increase in NPV for the second period, nearly twice that of

Table 5.8 Percentage Change in NPV from Baseline Values, Overall and by Decade, for Selected Scenarios.

SCENARIO	OVERALL	DECADE 1	DECADE 2	DECADE 3
C.2b	-1.416	-4.692	2.367	0.766
C.4b	1.103	-0.782	3.958	1.247
D.2b	-0.352	-2.342	2.119	0.687
D.4b	1.127	0.643	2.133	0.719

D.4b. This ratio decreases only slightly in the third period, though both scenarios show the waning impacts of the early increases in spawning.

Interestingly, both approaches to harvest restriction reveal patterns in the their inter-generational returns similar to those of their distribution of returns between harvest parties. The restrictions of C.4b were characterized by large losses to one party and large gains to the others, while those of D.4b obtained roughly the same net result with much more moderated impacts to individual harvest parties. Likewise, the C.4b restrictions produce far greater swings in inter-generational NPV than do those of D.4b.

Finally, as a demonstration of how the model may be used assess the importance of the choice of discount rate, these same four scenarios were re-run using 3.0 and 2.0 discount rates. The NPV results, in annuity form are shown in Table 5.9.

Since all of these harvest scenarios are designed to sacrifice some current harvest in order to increase that in the future, it is not surprising that the NPV's show steady improvement in all cases as the discount rate is reduced. The magnitude of the increases, however, is not substantial. The reduction in the discount rate from 4.6 to 2.0 percent produces an increase of less than one percent in the four scenario results relative to the baseline case.

Table 5.9 Differences from Baseline Annuity Values for Selected Scenarios Using Various Discount Rates.

	DISCOUNT RATE		
SCENARIO	4.6 PERCENT	3.0 PERCENT	2.0 PERCENT
C.2b	-29,159	-19,709	-14,228
C.4b	22,722	28,691	31,861
D.2b	-7,254	-1,297	2,071
D.4b	23,217	24,845	25,603

In summary, restriction of harvest rates through the use of a minimum passage requirement produced a pattern in NPV change similar to that witnessed in Application C. Imposition of the restrictions only in the ocean fishery again produced the most beneficial overall effects. In this case, however, the redistributive impacts of the harvest reduction were lessened.

Comparison was made of the time path of benefits for selected scenarios from applications C and D. This analysis confirmed that a blanket reduction in current harvest rates would be more effective in producing increased benefits in future decades, but at the cost of reduced benefits during the current decade. Analysis of several scenarios using two lower discount rates yielded conclusions which were, in general, similar to those obtained with a 4.6 rate.

Application E - The Effects of Joint Changes in Ocean Harvest and Up-stream Passage Rates

Application E provides a systematic mapping of the individual and joint effects of a change in river passage and a change in the ocean harvest rates. The ocean harvest rates at Node 8 are varied between minus five and plus five percent of the baseline rate at one percent increments. For each of these 11 cases the upstream passage rates at Savage Rapids Dam (Node 12) are also varied over the same range of percentage adjustments. This testing yields NPV estimates for a total of 121 scenarios.

The results of this testing are analyzed for non-linearities in the interactive influences of these two different model components on NPV. (In addition, inference is drawn, using the baseline parameters for Node 12, on the extent to which alterations in long run ocean harvest rates would facilitate the provision of additional harvest to an upriver fishery.)

Table 5.10 contains three blocks of data derived from the analysis of the NPV results for the scenarios of Application E. The first block shows the proportional difference between the NPV for each parameter pair and the NPV for the baseline case. The element in the upper left-hand corner of the block indicates that when both parameters are reduced by five percent, the NPV obtained is 4.006 percent less than that of the baseline case. Accordingly, the central element--along the 0-0 axes--is "0", since this combination represents the baseline case. It should be noted that NPV for changes in passage rate does not include a cost component for attaining the new rate of passage.

As expected from the results reported in Application C, NPV exhibits a negative correlation with changes in the ocean harvest rate. These results demonstrate that even in the absence of factors altering river migratory ability, increasing

Table 5.10 Net Present Value Results for Application E.

CHANGE IN HARVEST RATE / CHANGE IN PASSAGE RATE	-5%	-4%	-3%	-2%	-1%	0%	+1%	+2%	+3%	+4%	+5%
					PROPORTIONAL CHANGE IN NPV FROM A.3						
-5%	-.04006	-.04064	-.04127	-.04192	-.04260	-.04330	-.04402	-.04475	-.04550	-.04628	-.04706
-4%	-.03132	-.03186	-.03246	-.03310	-.03378	-.03450	-.03524	-.03600	-.03678	-.03758	-.03840
-3%	-.02267	-.02320	-.02377	-.02438	-.02503	-.02573	-.02647	-.02725	-.02805	-.02888	-.02972
-2%	-.01408	-.01461	-.01517	-.01576	-.01639	-.01706	-.01777	-.01853	-.01933	-.02017	-.02104
-1%	-.00563	-.00611	-.00664	-.00722	-.00784	-.00849	-.00918	-.00991	-.01069	-.01150	-.01237
0	.00270	.00226	.00177	.00123	.00064	.00000	-.00068	-.00139	-.00213	-.00293	-.00377
+1%	.01096	.01051	.01005	.00954	.00900	.00840	.00775	.00705	.00632	.00555	.00473
+2%	.01915	.01873	.01826	.01776	.01723	.01667	.01606	.01541	.01469	.01393	.01314
+3%	.02718	.02681	.02639	.02591	.02539	.02483	.02424	.02362	.02294	.02223	.02145
+4%	.03509	.03476	.03438	.03395	.03347	.03293	.03235	.03173	.03108	.03040	.02966
+5%	.04286	.04256	.04223	.04185	.04141	.04091	.04037	.03977	.03913	.03845	.03774
					DIFFERENCE BETWEEN LINEAR APPROXIMATION AND ACTUAL CHANGE						
-5%	.00055	.00040	.00026	.00015	.00006	.00000	-.00004	-.00006	-.00007	-.00004	.00002
-4%	.00048	.00038	.00027	.00017	.00007	.00000	-.00007	-.00012	-.00015	-.00014	-.00012
-3%	.00036	.00027	.00019	.00012	.00005	.00000	-.00007	-.00013	-.00019	-.00022	-.00022
-2%	.00028	.00019	.00012	.00007	.00003	.00000	-.00004	-.00008	-.00014	-.00017	-.00020
-1%	.00016	.00013	.00008	.00004	.00000	.00000	-.00001	-.00004	-.00006	-.00008	-.00011
0	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
+1%	-.00014	-.00014	-.00012	-.00009	-.00005	.00000	.00003	.00003	.00005	.00008	.00010
+2%	-.00022	-.00020	-.00017	-.00014	-.00008	.00000	.00007	.00012	.00016	.00020	.00024
+3%	-.00034	-.00027	-.00020	-.00015	-.00008	.00000	.00009	.00017	.00025	.00034	.00039
+4%	-.00054	-.00043	-.00032	-.00022	-.00010	.00000	.00010	.00018	.00028	.00040	.00050
+5%	-.00075	-.00061	-.00045	-.00030	-.00014	.00000	.00014	.00024	.00035	.00047	.00060
					ERROR OF APPROXIMATION AS A PERCENTAGE OF THE ACTUAL CHANGE						
-5%	-1.36618	-.99344	-.64030	-.35788	-.13236	.00000	.08495	.13963	.15169	.08745	-.03242
-4%	-1.54466	-1.18609	-.83602	-.50719	-.21386	.00000	.18722	.33144	.40657	.38360	.32515
-3%	-1.58503	-1.17026	-.79773	-.48231	-.21359	.00000	.25301	.49308	.68038	.74926	.74161
-2%	-1.97131	-1.30663	-.79359	-.44451	-.18455	.00000	.19733	.42974	.71178	.85901	.95821
-1%	-2.89219	-2.06365	-1.25609	-.48600	-.07191	.00000	.11370	.37941	.59796	.66660	.85366
0	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000	.00000
+1%	-1.28498	-1.36320	-1.22627	-.93627	-.50846	.00000	.34006	.49309	.75632	1.41002	2.20770
+2%	-1.13098	-1.05528	-.95152	-.78859	-.44748	.00000	.44067	.80350	1.06680	1.42255	1.84491
+3%	-1.25339	-1.01931	-.76981	-.56327	-.31203	.00000	.37979	.73641	1.09339	1.51115	1.83241
+4%	-1.55038	-1.22324	-.92290	-.63867	-.31047	.00000	.29678	.57429	.90809	1.30165	1.67206
+5%	-1.75159	-1.43664	-1.07109	-.70544	-.34071	.00000	.33486	.61588	.90069	1.22349	1.58197

ocean harvest rates may diminish the value of the salmon resource. Also intuitively sensible is the positive correlation seen between NPV and changes in the upstream passage rate.

The results indicate that changes in an in-stream passage rate have a significantly greater affect upon NPV than do comparable percentage changes in ocean harvest rate. Reducing the passage rate by one percent diminished NPV by an amount 12.5 times loss caused by a proportional increase in the harvest rate. This factor increased to 14.5 for joint five percent parameter changes.

Some of this difference in impact might appear to stem from differences in the magnitude of the rate coefficients for harvest and passage. The baseline harvest rates for both wild and hatchery fish in the ocean are "0.33", while the passage rates at Node 12 average "0.84" over both stocks. Increasing the former by five percent adds only 0.0165 to that parameter, while a proportional increase to the latter adds 0.042 to the passage rate.

Thus, there is a 2.5-fold difference in the range of the parameters used in this application. On the other hand, the number of fish affected at the point of ocean harvest is--on average in the baseline case--69,350, while only 32,360 for passage at Node 12. Using these averages, 1,144 additional fish would be removed by harvest at Node 7 as a result of a five percent increase in the ocean harvest rate. By comparison, 1,355 additional fish would die at Node 12 with a 5 percent decrease in passage there. It is therefore likely that the differences in rate magnitude and the number of fish affected at each node largely offset one another.

A more probable account of this difference in magnitude lies in the way changes in each parameter increases or decreases NPV. When the harvest rate is decreased, more fish are made available for in-stream harvest in the same year, but at the expense of the ocean fishery. Even though more fish will spawn as a result, the additional offspring will still be subjected to lower ocean harvest rates. Thus the increased NPV realized by the in-stream fishery is moderated by the loss of value from ocean harvest. This can be seen in Table 5.11, which shows the proportional change in NPV for each harvest party from that of the base case. Table 5.11 will be more thoroughly reviewed following the current analysis of Table 5.10.

When the passage rate is increased, more fish are made available to the furthest up-stream fishery in the same year, but no other harvest group has sacrificed value in order to facilitate this gain. In addition, when the offspring of the larger number of spawners are ready for harvest, all of the harvest parties reap the full benefit. In other words, there is an unconditional gain for all users.

Table 5.11 Proportional Change in NPV from Baseline Values, by Harvest Party, for Application E.

CHANGE IN HARVEST RATE		-5%	-4%	-3%	-2%	-1%	0%	1%	2%	3%	4%	5%
CHANGE IN PASSAGE RATE	HARVEST PARTY											
-5%	1	-.0643	-.0572	-.0502	-.0433	-.0364	-.0296	-.0229	-.0162	-.0096	-.0031	.0034
	2	.0090	.0012	-.0066	-.0143	-.0221	-.0298	-.0376	-.0452	-.0528	-.0604	-.0680
	3	-.0418	-.0493	-.0567	-.0641	-.0715	-.0789	-.0863	-.0937	-.1010	-.1083	-.1156
-4%	1	-.0585	-.0513	-.0443	-.0372	-.0303	-.0235	-.0167	-.0100	-.0034	.0032	.0097
	2	.0152	.0074	-.0003	-.0081	-.0159	-.0236	-.0314	-.0391	-.0468	-.0545	-.0621
	3	-.0256	-.0331	-.0406	-.0482	-.0557	-.0632	-.0707	-.0782	-.0856	-.0930	-.1004
-3%	1	-.0529	-.0457	-.0385	-.0314	-.0243	-.0174	-.0106	-.0038	.0029	.0095	.0160
	2	.0213	.0135	.0057	-.0020	-.0098	-.0176	-.0253	-.0331	-.0408	-.0485	-.0562
	3	-.0094	-.0170	-.0246	-.0322	-.0398	-.0474	-.0550	-.0626	-.0701	-.0777	-.0852
-2%	1	-.0474	-.0401	-.0328	-.0256	-.0185	-.0116	-.0046	.0023	.0091	.0157	.0223
	2	.0272	.0195	.0117	.0040	-.0038	-.0116	-.0193	-.0271	-.0348	-.0426	-.0503
	3	.0068	-.0009	-.0086	-.0163	-.0239	-.0316	-.0392	-.0469	-.0546	-.0623	-.0699
-1%	1	-.0421	-.0346	-.0272	-.0200	-.0128	-.0057	.0013	.0083	.0151	.0219	.0286
	2	.0330	.0253	.0176	.0098	.0020	-.0057	-.0135	-.0212	-.0290	-.0367	-.0445
	3	.0229	.0152	.0075	-.0003	-.0081	-.0158	-.0235	-.0313	-.0390	-.0468	-.0545
0%	1	-.0369	-.0293	-.0218	-.0145	-.0072	.0000	.0071	.0141	.0211	.0279	.0347
	2	.0387	.0310	.0232	.0155	.0078	.0000	-.0078	-.0155	-.0233	-.0310	-.0388
	3	.0391	.0313	.0235	.0157	.0078	.0000	-.0078	-.0156	-.0235	-.0313	-.0391
1%	1	-.0318	-.0241	-.0166	-.0091	-.0017	.0056	.0128	.0199	.0269	.0338	.0407
	2	.0442	.0365	.0288	.0211	.0133	.0056	-.0022	-.0099	-.0177	-.0254	-.0332
	3	.0552	.0473	.0394	.0316	.0237	.0158	.0079	.0000	-.0079	-.0158	-.0237
2%	1	-.0268	-.0191	-.0114	-.0039	.0036	.0110	.0183	.0255	.0326	.0396	.0466
	2	.0497	.0419	.0342	.0265	.0188	.0110	.0033	-.0044	-.0122	-.0199	-.0277
	3	.0713	.0634	.0554	.0474	.0395	.0315	.0236	.0156	.0076	-.0003	-.0083
3%	1	-.0219	-.0141	-.0064	.0012	.0088	.0162	.0236	.0309	.0381	.0453	.0523
	2	.0549	.0472	.0395	.0318	.0241	.0163	.0086	.0009	-.0068	-.0146	-.0223
	3	.0874	.0794	.0714	.0633	.0553	.0472	.0392	.0312	.0231	.0151	.0070
4%	1	-.0172	-.0093	-.0015	.0062	.0139	.0214	.0289	.0362	.0435	.0508	.0579
	2	.0600	.0524	.0447	.0370	.0293	.0216	.0138	.0061	-.0016	-.0093	-.0171
	3	.1034	.0953	.0873	.0792	.0711	.0630	.0548	.0467	.0386	.0305	.0224
5%	1	-.0127	-.0047	.0032	.0111	.0188	.0264	.0340	.0415	.0488	.0561	.0633
	2	.0649	.0573	.0497	.0420	.0343	.0266	.0189	.0112	.0035	-.0043	-.0120
	3	.1193	.1111	.1030	.0949	.0868	.0786	.0704	.0623	.0541	.0459	.0377

Upon initial inspection, any particular element of the first block appeared to be closely approximated by the sum of the elements from the "0-0" axes for the same row and column. Block 2 of Table 5.10 shows, for each element, the difference between the actual value in block 1 and the sum of the relevant "0-0" elements. Again using the upper-left element as an example, the sum of the "0-0" elements is .00270 + (-.04330) = -.04060. Subtracting this from the actual block 1 value gives -.04006 - (-.04060) = .00055, with an allowance for rounding. As can be seen in block 2, none of these approximations differs from the block 1 value by more than .00075.

Block 3 shows the error in the approximation--i.e. difference from zero--as a percentage of the original block 1 value. Negative values in block 3 indicate that the absolute value of the approximation was greater than the absolute value of the original. Immediately apparent is the fact that when the harvest rate is reduced, the actual change in value is less than predicted by the approximation, while the reverse is true when the harvest rate is increased. Indeed, there is a consistent pattern of increase in the proportional magnitude of the approximation, relative to the original, as the harvest rate is increased.

Movement along the columns of block 3--representing changes in passage rate--does not reveal the same consistent pattern. In general, it appears that as the change in the passage rate increases in magnitude, the approximation approaches the value of the original. The most pronounced exception to this pattern occurs with the largest increases to the passage, particularly in the lower-left quadrant. For those values the actual change becomes increasingly smaller than predicted as the passage rate is increased.

The most likely explanation for this would seem to be that as the passage rate is increased significantly--particularly when reductions in ocean harvest have also made more fish available for up-stream passage--the marginal improvement of NPV is reduced because of the natural carrying capacity of spawning grounds.

Having greater numbers of fish reaching the spawning grounds may mean that the carrying capacity for eggs is exceeded, hypothetically, once every five years as opposed to once every ten. If such were the case, then for one year in ten no regenerative benefit would accrue, and for one additional year the benefit would be only partially realized.

Table 5.11 shows the proportional change in NPV for each of the harvest parties for all of the parameter pairs. As expected, changes in the ocean harvest rate produce opposing responses in the values of the ocean and river fisheries. Decreasing the harvest rate consistently reduces the value of the ocean harvest while increasing the value of both the lower and upper river harvests. As with the overall NPV results, the range of change in harvest party NPV on either side of the baseline harvest rate column remains fairly constant throughout the set of passage rate changes. Increasing the up-stream passage rate consistently improves the NPV's of all harvest parties.

Theoretically, the values presented in Tables 5.10 and 5.11 could be used to identify changes in management policy yielding Pareto improvements. Assume, for example, that it is technologically possible to achieve a maximum three percent increase in the return passage rate at Savage Rapids Dam. If the ocean harvest rate remains unchanged this implies a 2.483 percent increase in the NPV of fish harvested (from Table 5.10, block 1).

Further reference to Table 5.11, however, indicates that the ocean harvest rate may be adjusted up to two percent in either direction without reducing the NPV of any of the harvest parties. If maximizing total NPV were the desired conditional goal, ocean harvest could be reduced by two percent, producing an additional 0.108 percent increase to total NPV, while keeping all groups at least as well off as they were before the changes.

In summary, changes in river passage rates appear to have a much greater influence on NPV than do adjustments in ocean harvest rates. The effects of joint changes in these rates are approximated well by a linear sum of individual impacts, though this may be attributable in large part to the design of the model. Finally, an illustration was presented of how the model can be used to survey the distributive, as well as the efficiency, impacts of proposed policy changes.

CHAPTER 6 - CONCLUSION

Anadromous fish populations in the Pacific Northwest have undergone substantial change throughout the past century. Runs of naturally spawning salmonids have been diminished by a combination of factors including, most notably, the removal or degradation of habitat and historical periods of over-harvest.

Government agencies have attempted to mitigate these losses through increasing releases of hatchery-reared smolts. Even with the addition of these hatchery fish, however, many fisheries do not appear able to sustainably produce the volume of catch they once did.

Some of the difficulties of managing salmonid populations--as they migrate through numerous political jurisdictions and environmental conditions--may be eased by increasing the availability of tools which simulate salmon life-cycles and values derived by society from their use. Previous modeling efforts have aimed primarily at providing managers with information regarding biological outcomes. This thesis has attempted to expand the focus of the simulation modeling approach to include the estimation of the economic impacts of decisions. The availability of this kind of economic information may be valuable for the scaling of projects and for understanding who gains and loses under various policy alternatives.

Motivated by a belief that modeling can contribute to improved management of anadromous fish resources, this research has pursued the design of an accessible computer-based simulation model and the application of this model to some relevant fishery management issues.

The model characterizes the migratory journey of salmonids as movements throughout a series of nodes. Through a data input file, a user specifies, among other things, the structure of nodes, parameters governing the movement of fish throughout the network, the location and extent of harvest activities, and the values associated with harvested fish. Additionally, the model has the ability to reflect the stochastic nature of many factors represented by model parameters.

Wild and hatchery stocks of spring chinook salmon of the Rogue River in southern Oregon were selected for study using this model. Following the development of a set of "baseline" parameters, estimated model values were compared with historical figures for catch and escapement. Mean values for escapement and pounds of fish harvested, for each of three defined harvest parties, were all within six percent of the actual figures for 50 30-year simulations.

The variance in estimated escapement was considerably smaller than that witnessed in the historical data--6,900 versus 11,100 fish. This aspect of the model's simulation capability deserves further attention. It is possible that the ability to specify additional density-dependent relationships within the model might improve its performance in this regard. Other features which could facilitate improved modeling are discussed below.

The goal in developing the model was not that it should exhaustively include all of the relevant biological factors affecting salmonids of a particular basin, but that it should be capable of utilizing the most important factors under a variety of basin settings. In light of this, five sets of applications were devised to illustrate the usefulness of the model in providing economic information about policy/project alternatives. The results obtained from these applications will be indicative of real world outcomes only to the extent that biological and economic factors specific to Rogue River spring chinook have been realistically represented.

Application A examined the construction of Lost Creek Dam and a companion hatchery on the upper Rogue. The loss in fish-generated value from stocks subsequently unable to spawn above the dam was estimated at roughly $10,600,000, using a 4.6 percent discount rate over 30 years. This estimate reflects a commercial surplus value of 90 percent of ex-vessel price and is equivalent to an annuity (loss) of $660,000 over the 30-year time period. Lowering the commercial value to 50 percent of ex-vessel price reduced the overall loss to about $8,800,000.

Hatchery releases following the completion of the dam--800,000 smolts--were not sufficient to mitigate this lost value, given a similar allocation of catch among harvest parties. On the other hand, 1985-86 levels of release--1,600,000 smolts--are estimated to generate NPV greater than that existing before the dam's construction with either commercial value, as long as the benefits to fishermen are not reduced operational costs of the hatchery. When the cost of hatchery operations is subtracted from the value received by fishermen, the percentage of ex-vessel price used strongly influences any conclusions as to whether the hatchery has replaced the social value lost because of the dam.

The second application (B) examined more closely the effects of changes in hatchery policy. One and five percent changes in the level of hatchery output--from the baseline case--maintained over a 30-year period were characterized by three-to-one benefit/cost ratios. The estimated elasticity of the value of harvested hatchery fish to changes in 30-year hatchery expenditures was roughly 0.88.

The value derived from additional juveniles--equal to the number that would be produced by a typical four-year old spawning female--was estimated for wild spawning and hatchery release. The value of one more wild female was $284 and $319 using discount rates of 4.6 and 3.0 respectively. Comparable increase in hatchery release produced less than half of this value, primarily because the resulting increased escapement of hatchery adults did not add to the release levels in subsequent generations of hatchery smolts.

The third (C) and fourth (D) applications examined the effects of different types of harvest restrictions on the overall value of harvests and the distribution of benefits between harvest parties. Application C utilized a direct reduction in the harvest rate parameter for the ocean and up-river harvest parties, individually and jointly.

Reduction of the harvest rates for up-river fishermen resulted in a decrease in NPV, while comparable reductions in the ocean harvest rate increased NPV. This difference in impact is primarily attributable to 1) the higher value of sport-caught fish, and 2) the sequential characteristics of the harvest activities.

In the fourth application harvest rates for the same fisheries were reduced only when necessary to meet minimum requirements for the number of fish entering the following model node. A similar pattern was observed in the relationship between the location of restriction implementation and the qualitative response of NPV.

Basing the reductions in harvest on a measure of the available fish, however, produced much milder variations in the benefits accruing to individual harvest parties, for a given change in overall NPV. Comparison of results from these two applications points to the importance of improving our ability to use forecasts of abundance as a means of determining harvest restrictions. While the restricted cases showed improved NPV relative to the baseline case as the discount rate was lowered, the magnitude of this improvement was not significant.

The final application explored the individual and joint effects on NPV of changes in ocean harvest rate and return passage rate at the furthest dam downstream. Changes in upstream passage ability were seen to have a much greater impact on NPV than ocean harvest changes of comparable proportion--though there was no attempt made to assign a cost to the facilitation of the passage rate change. For example, a five percent reduction in ocean harvest rate increased NPV by only 0.27 percent, while a five percent increase in the dam passage rate resulted in a 4.09 percent increase in NPV.

The effects of joint changes in both parameters was very closely approximated by the sum of the individual effects from each parameter change. Finally, it was demonstrated that using results for both overall and individual party benefits, policies could be subjected to pareto-improvement considerations as well as those of increasing overall NPV.

Implications For Further Research

The model developed during this research has some notable limitations for analysis of some types of management concerns. Because it cycles fish through the node structure on a yearly basis, it is not well-suited to address issues requiring the analysis of migration and harvest in smaller time intervals.

As mentioned in chapter 4, the structure of the model, currently, does not allow juveniles to remain in fresh water for additional years, or to return to the sea after spawning. If the model is to be used for analysis of steelhead populations, these limitations will have to be addressed.

In addition, there are several biological and economic factors whose inclusion would likely enhance the performance and usefulness of the model. The model currently treats "species" quite separately. Since hatchery and wild stocks must be entered into the model as separate species if they are to have different passage or harvest parameters, the addition of linkages between species would be desirable. Such linkages might include joint-species harvest restrictions and predation of wild fry by hatchery releases.

As mentioned above, the capability of introducing a density-dependent survival relation between the smolt and adult stages in the model is probably also desirable. This addition could facilitate an increase in the variance of quantities of returning fish without enlarging the range of values.

At the same time, this kind of modeling effort would be greatly facilitated by the development of more consistent and detailed time-series of data regarding the survival of salmon from stage to stage of the life cycle.

Finally, adding to the model the capability to utilize supply and demand curve information--i.e. allowing societal value per fish to be specified as a function of the number of fish caught--will increase the reliability of economic estimates, provided that the parameters of such a value-quantity relationship can be identified. More research is needed to improve the specification of these per-fish value relationships, not only for commercially harvested fish, but also for those caught by sport fishermen.

These improvements are, on the whole, relatively minor considerations compared to the model's ability to translate changes in generally specified environmental and use parameters into estimates of economic impact. The ease and accuracy with which the model can be applied to basins less studied than the Rogue is yet to be seen. Where funding is available, development of a basin-specific model may be a superior alternative. But, where available management resources cannot support model development, use of this model may prove an efficient alternative for estimating the economic effects of project and policy alternatives.

BIBLIOGRAPHY

Bonneville Power Administration (BPA). Stock Assessment of Columbia River Anadromous Salmonids, Final Report 1984, September 1985.

Brown, William G., and Faisal M. Shalloof. "Recommended values for Columbia River Salmon and Steelhead for Current Fishery Management Decisions." Paper prepared for NMFS/NOAA in conjunction with contract 43ABNF5 2904, March 1986.

Brown, W.G., C.N. Sorhus, and K.C. Gibbs. Estimated Expenditures by Sport Anglers and Net Economic Values of Salmon and Steelhead for Specified Fisheries in the Pacific Northwest, Dept. of Agricultural and Resource Economics, Oregon State University, 1980.

Cochran, William G. Sampling Techniques, John Wiley and Sons, New York, 1977.

Cramer, Stephen P., and Barry P. McPherson. Annual Report -- Rogue Basin Fisheries Evaluation Program. Oregon Department of Fish and Wildlife, July 1982.

Crutchfield, J.A., S. Langdon, O.A. Mathisen, and P.H. Poe. The Biological, Economic, and Social Values of a Sockeye Salmon Stream in Bristol Bay, Alaska: a case study of Tazimina River, Circular No. 82-2, Fisheries Research Institute, University of Washington, 1982.

Dorratcaque, Dennis E. Lemhi River Habitat Improvement Study. Bonneville Power Administration, December 1985.

Evenson, M.D. and R.D. Ewing. Annual Progress Report -- Cole Rivers Hatchery Evaluation. Oregon Department of Fish and Wildlife, June 1984.

Fish Commission of Oregon. Research Reports of the Fish Commission of Oregon, 4:1, March 1973.

Hilborn, Ray, Carl J. Walters, Randall Peterman, and Michael J. Staley. "Models and Fisheries: A Case Study in Implementation." North American Journal of Fisheries Management, (1984) 9-14.

Huppert, D.D., R.D. Fight, and F.H. Everest. Economic Considerations in Forest and Rangeland Management Effects on Anadromous Fish Habitat, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Corvallis, Oregon, 1984.

Just, Richard E., Darrell L. Hueth, and Andrew Schmitz. Applied Welfare Economics and Public Policy, Prentice-Hall (Englewood Cliffs), 1982.

Larkin, P.A. "Pacific Salmon." Fish Population Dynamics, ed. J.A. Gulland, Wiley, New York,1977.

Larkin, P.A. and A.S. Hourston. "A Model for Simulation of the Population Biology of Pacific Salmon," Journal of the Fisheries Research Board of Canada, 21 (1964): 1245-1265.

Lichatowich, J.A. Rogue Basin Fisheries Evaluation Program, Quarterly Reports, Oregon Department of Fish and Wildlife, 1975.

Lind, Robert C. "A Primer on the Major Issues Relating to the Discount Rate for Evaluating National Energy Options," Discounting for Time and Risk in Energy Policy, Resources for the Future (Washington), 1982.

Loeffel, Robert E. and Henry O. Wendler. Review of the Pacific Coast Chinook and Coho Salmon Resources with Special Emphasis on the Troll Fishery, Informal Committee on Chinook and Coho--United States working group, April 1968.

Loomis, John B., and William G. Brown. "The Use of Regional Travel Cost Models to Estimate the Net Economic Value of Recreational Fishing at New and Existing Sites," Making Economic Information More Useful for Salmon and Steelhead Production Decisions, NOAA Technical Memorandum NMFS F/NWR-8, Portland, Oregon, 1985.

McCarl, B.A. and R.B. Rettig. "Economic Information for Long and Short Term Salmon and Steelhead Project Analysis: Issues and Requirements." Making Economic Information More Useful for Salmon and Steelhead Production Decisions, NOAA Technical Memorandum NMFS F/NWR-8, Portland, Oregon, 1985.

Meyer, P.A. Net Economic Values for Salmon and Steelhead from the Columbia River System, NOAA Technical Memorandum NMFS F/NWR-3, Portland, Oregon, 1982.

Mishan, E.J. Cost-Benefit Analysis, Praeger (New York), 1976.

Northwest Power Planning Council (NWPPC). Compilation of Information on Salmon and Steelhead losses in the Columbia River Basin, March 1986.

Oregon Department of Fish and Wildlife. Comprehensive Plan for Production and Management of Oregon's Anadromous Salmon and Trout, June 1, 1982.

Oregon Department of Fish and Wildlife. Rogue Basin Fisheries Evaluation Program, Adult Salmonid Studies, Progress Report, eds. S.P. Cramer and B. McPherson, July 1983.

Pacific Fishery Management Council. 1984 Ocean Salmon Fisheries Review, March 1985.

Pacific Northwest River Basins Commission (PNWRBC). Status of Columbia River Salmon and Steelhead Trout, August 1972.

Poon, D. and J. Garcia. A Comparative Analysis of Anadromous Salmonids Stocks and Possible Cause for Their Decline in Selected Watersheds of the Eastern Pacific Coast, Final Report, Northwest Power Planning Council, June 1982.

Randall, Alan. Resource Economics: An Economic Approach to Natural Resource and Environmental Policy, Grid, Columbus, 1981.

Rettig, R. Bruce, and Bruce A. McCarl. "Potential and Actual Benefits from Commercial Fishing Activities," Making Economic Information More Useful for Salmon and Steelhead Production Decisions, NOAA Technical Memorandum NMFS F/NWR-8, Portland, Oregon, 1985.

Satterthwaite, T.D., B.P. McPherson, P.A. Frazier and S.P. Cramer. Biennial Progress Report -- Rogue Basin Fisheries Evaluation Program, Lost Creek Dam Studies, Oregon Department of Fish and Wildlife, November 1985.

Stevens Joe B. and Bruce W. Mattox. "Augmentation of Salmon Stocks Through Artificial Propagation: Methods and Implications." Ocean Fishery Management: Discussions and Research, NOAA Technical Report NMFS CIRC-371, ed. Adam A. Sokolowski, National Marine Fisheries Service, April 1973.

U.S. Army Corps of Engineers, Walla Walla District. A Methodolgy for Estimating Fishery Benefits for Galloway Dam and Reservoir, Weiser River, Idaho, Draft Report, July 1985.

Van Hyning, Jack M. "Factors Affecting the Abundance of Fall Chinook Salmon in the Columbia River," Research Reports of the Fish Commission of Oregon, Fish Commission of Oregon, March 1973.

Walters, Carl J. and Peter Cahoon. "Evidence of Decreasing Spatial Diversity in British Columbia Salmon Stocks," Canadian Journal of Fisheries and Aquatic Sciences, 42(1985):1033-1037.

APPENDICES

APPENDIX A

Pascal Source Code for the Computer Simulation Model

```
{   This is an MS-PASCAL simulation program for modeling salmon
management alternatives developed by James Hastie, Andy Lau, and
Bruce McCarl. }

PROGRAM Fish_Model ( INPUT, OUTPUT );

CONST   MAX_SPECIES = 6;   MAX_BENODE = 6;
        MAX_HARVEST = 6;   MAX_LAG    = 5;
        MAX_NODE    = 21;
        OUT = 3;  BACK = 5;
        YES = 'Y';  NO = 'N';

TYPE    FISH = RECORD
               NAME : STRING(20);
               FYH  : INTEGER;
               LYH  : INTEGER;
               STH  : INTEGER;
               DELAY: ARRAY [0..MAX_LAG ] OF REAL;
               RELAY: ARRAY [0..MAX_LAG ] OF REAL;
               WTYR : ARRAY [1..MAX_LAG, 1..MAX_HARVEST] OF REAL;
              END;

        DATA = RECORD
                NAME    : STRING(30);
                ORDER   : INTEGER;
                NEXT    : INTEGER;
                BRANCH  : ARRAY [1..3] OF INTEGER;
                STPR    : ARRAY [1..MAX_SPECIES] OF INTEGER;
                PARTIES: INTEGER;
                PWHR    : ARRAY [1..3] OF INTEGER;
                PWHRST  : ARRAY [1..3,1..MAX_SPECIES] OF INTEGER;
                MINFISH: ARRAY [0..MAX_SPECIES] OF REAL;
                BEFLAG  : INTEGER;
                SPLIT   : ARRAY [1..3] OF INTEGER;
           HFLAG  : ARRAY [1..MAX_HARVEST] OF INTEGER;
               END;

   BEGINNING = RECORD
                  LOCATE : INTEGER;
                  SMOLTSF: ARRAY [1..MAX_SPECIES] OF INTEGER;
                  MINEGGS : ARRAY [1..MAX_SPECIES] OF REAL;
                  MAXEGGS  : ARRAY [1..MAX_SPECIES] OF REAL;
               END;

      ENDING = RECORD
              LOCATE : INTEGER;
              BEGNODE: INTEGER;
```

```
          FEMALE : ARRAY [1..MAX_SPECIES,0..MAX_LAG] OF REAL;
           END;

     PHFLAG = RECORD
          PASSAGE: ARRAY [1..MAX_NODE] OF REAL;
          PDHR   : ARRAY [1..MAX_NODE,1..3] OF REAL;
         SPECIAL: ARRAY [1..MAX_NODE,1..MAX_HARVEST] OF REAL;
          END;

      YEARS = RECORD
        FISHVALUE : ARRAY [1..MAX_HARVEST,0..MAX_LAG] OF REAL;
          END;

      RIVER = RECORD
              FACTOR : ARRAY [1..MAX_SPECIES] OF INTEGER;
              TABLE  : ARRAY [1..MAX_SPECIES,1..10] OF REAL;
              MEAN   : REAL;
              STDV   : REAL;
           END;

  PARAMETER = RECORD
          DISTRIBUTION : INTEGER;
          PH_RATE      : ARRAY [1..MAX_SPECIES,1..2] OF REAL;
           END;

       POND = RECORD
              SPECIES : ARRAY [1..MAX_SPECIES] OF REAL;
           END;

     REPROD = RECORD
                 ECON  : REAL;
         EMULT : REAL;
         MULT  : REAL;
          END;

      FISHS = ARRAY [1..MAX_SPECIES]  OF FISH;
    PARTIES = ARRAY [1..MAX_HARVEST]  OF STRING(30);
INFORMATION = ARRAY [1..MAX_NODE]     OF DATA;
  NODEBEGIN = ARRAY [1..MAX_BENODE]   OF BEGINNING;
     NODEND = ARRAY [1..MAX_BENODE]   OF ENDING;
       FLAG = ARRAY [1..MAX_SPECIES]  OF PHFLAG;
  YRHARVEST = ARRAY [1..MAX_SPECIES]  OF YEARS;
    PROJECT = ARRAY [1..MAX_NODE]     OF PARAMETER;
    POINTER = ARRAY [1..MAX_NODE]     OF INTEGER;
   PASSRATE = ARRAY [1..MAX_SPECIES]  OF REAL;
    LAGYEAR = ARRAY [0..MAX_LAG]      OF REAL;
        AGE = ARRAY [0..MAX_LAG,1..MAX_SPECIES]     OF REAL;
```

```
        TREE = ARRAY [1..MAX_SPECIES,1..MAX_NODE]    OF REAL;
       FIELD = ARRAY [1..MAX_SPECIES,1..MAX_HARVEST] OF REAL;
     PATTERN = ARRAY [0..MAX_LAG,1..MAX_LAG]         OF POND;
       STOCK = ARRAY [1..MAX_LAG,1..MAX_BENODE]      OF POND;
      HARVAL = ARRAY [1..MAX_SPECIES,1..MAX_HARVEST,1..50] OF
                  REAL;
      DISVAL = ARRAY [1..MAX_HARVEST]                OF REAL;
          SPAWN  = ARRAY [1..MAX_SPECIES]                OF
REPROD;

VAR   SPECIES       : FISHS;
      NODE          : INFORMATION;
      BEGNODE       : NODEBEGIN;
      ENDNODE       : NODEND;
      FLAGPH        : FLAG;
      HARVESTER     : PARTIES;
      HARVESTYR     : YRHARVEST;
      STOCHP, STOCHH                     : PROJECT;
      ENTER, LEAVE                       : TREE;
      RIVERUP, RIVERDW, UPWELLING        : RIVER;
      LEVEL, DSRL, FISHTOT, UPWFAC       : PASSRATE;
      HARVEST, TOTLBS, SUMTOT, DISTREAM : FIELD;
      HOLDING     : PATTERN;
      NEWSTOCK    : STOCK;
      ORDER       : POINTER;
      FISHAGE     : AGE;
      NUMBER_SPECIES, NUMBER_HARVEST       : INTEGER;
      NUMBER_BEGNODE, NUMBER_ENDNODE       : INTEGER;
      NUMBER_NODE, NUMBER_YEAR, YEAR       : INTEGER;
      NUMBER_STP, NUMBER_STH, GATE         : INTEGER;
      PTLAG, PTOUT, PERIOD, NUMBER_RUNS    : INTEGER;
      I, J, K, L, LAG, N, S, U, Z, FILES  : INTEGER;
      INPUTNAME, OUTPUTNAME, OUT2NAME, IN2NAME      : STRING(12);
      RANDSEED      : INTEGER4;
      F, G, H,E     : TEXT;
      ANSWER, ANSWER2               : CHAR;
      DISRATE, ALLLBS                      : REAL;
          REPRO         : SPAWN;
          HARVTOT       : DISVAL;
      DOLSTRM       : HARVAL;

PROCEDURE READ_PRICES( VAR HARVESTYR : YRHARVEST;
          NUMBER_SPECIES, NUMBER_HARVEST, LAG,PERIOD : INTEGER );

VAR       I, S, J : INTEGER;
BEGIN   { Read in the fish values in $/lb }
   FOR S := 1 TO NUMBER_SPECIES DO BEGIN
```

```
        FOR I := 1 TO NUMBER_HARVEST DO BEGIN
          FOR J := 0 TO PERIOD DO
            READ( F, HARVESTYR[S].FISHVALUE[I,J] );
            READLN( F );
        END; {FOR I }
    END;  { FOR S }
END;   { PROCEDURE READ_PRICES }

PROCEDURE READ_NODES( VAR NUMBER_NODE, NUMBER_SPECIES, GATE :
INTEGER;
VAR NODE : INFORMATION; VAR FLAGPH : FLAG;
VAR STOCHP, STOCHH : PROJECT );
VAR       I, J, K, M, N, S, L, P : INTEGER;
                         A, B, Q : REAL;
BEGIN  { Read in data for nodes (i.e. structure, passage and
harvest rates). }
   READLN ( F, NUMBER_NODE, GATE );
   FOR S := 1 TO NUMBER_NODE DO  BEGIN
       WRITELN( 'Reading node number ', S:3 );
       READLN( F, NODE[S].NAME  );
       READLN( F, NODE[S].ORDER );
       READLN( F, NODE[S].NEXT  );
       IF NODE[S].NEXT <> 0 THEN  BEGIN
          FOR J := 1 TO NODE[S].NEXT DO
              READLN( F, NODE[S].BRANCH[J] );
       END;
       FOR I := 1 TO NUMBER_SPECIES DO BEGIN
           READLN( F, J );
           NODE[S].STPR[I] := J;
           IF J = -1 THEN  BEGIN
              READLN( F, FLAGPH[I].PASSAGE[S] );
              END
           ELSE IF J = 0 THEN  BEGIN
              STOCHP[S].DISTRIBUTION := 0;
              READLN( F, A, B );
              STOCHP[S].PH_RATE[I,1] := A - B / 2.0;
              STOCHP[S].PH_RATE[I,2] := B;
             END
           ELSE IF J = 1 THEN  BEGIN
              STOCHP[S].DISTRIBUTION := 1;
              READLN( F, STOCHP[S].PH_RATE[I,1], B );
              STOCHP[S].PH_RATE[I,2] :=  B ;
           END;  { End If }
       END;  { FOR I }
       READLN( F, N );
       NODE[S].PARTIES := N;
       IF N <> 0 THEN BEGIN
```

```
            FOR K := 1 TO N DO  READLN( F, NODE[S].PWHR  [K] );
             FOR K := 1 TO N DO BEGIN
             READ( F, L );
            NODE[S].HFLAG[K] := L;
            IF L > 0 THEN BEGIN
            FOR P := 1 TO NUMBER_SPECIES DO BEGIN
            READ( F , Q );
            FLAGPH[P].SPECIAL[S,K] := Q;
            END; { FOR P }
            END; { if }
            READLN( F );
             END; { FOR K }
            FOR K := 1 TO N DO
                FOR I := 1 TO NUMBER_SPECIES DO  BEGIN
                    READLN( F, J );
                    NODE[S].PWHRST[K,I] := J;
                    IF J = -1 THEN  BEGIN
                       READLN( F, FLAGPH[I].PDHR[S,K] );
                       END
                    ELSE IF J = 0 THEN  BEGIN
                       STOCHH[S].DISTRIBUTION := 0;
                       READLN( F, A, B );
                       STOCHH[S].PH_RATE[I,1] := A - B / 2.0;
                       STOCHH[S].PH_RATE[I,2] := B;
                       END
                     ELSE IF J = 1 THEN  BEGIN
                       STOCHH[S].DISTRIBUTION := 1;
                       READLN( F, STOCHH[S].PH_RATE[I,1], B );
                       STOCHH[S].PH_RATE[I,2] :=  B ;
                     END;  { If }
                END; {FOR I }
         END;   { If }
         FOR I := 0 TO NUMBER_SPECIES DO
            READ( F, NODE[S].MINFISH[I] );
         READLN( F );
         READLN( F, NODE[S].BEFLAG  );
         IF NODE[S].NEXT > 1 THEN
            FOR J := 1 TO NODE[S].NEXT DO
               READLN( F, NODE[S].SPLIT[J] );
   END;  { FOR S }
END;   { PROCEDURE READ_NODES }

PROCEDURE READ_BEGNODE( VAR BEGNODE : NODEBEGIN;
                     NUMBER_SPECIES, NUMBER_BEGNODE : INTEGER );
VAR  I, L, S : INTEGER;
BEGIN  { Read in beginning node information }
   FOR S := 1 TO NUMBER_BEGNODE DO BEGIN
```

```
      READLN( F, BEGNODE[S].LOCATE );
      FOR I := 1 TO NUMBER_SPECIES DO
         READLN( F, BEGNODE[S].SMOLTSF[I] );
      FOR I := 1 TO NUMBER_SPECIES DO
         READLN( F, BEGNODE[S].MINEGGS[I] );
      FOR I := 1 TO NUMBER_SPECIES DO
         READLN( F, BEGNODE[S].MAXEGGS[I] );
   END;  { End of FOR Loop S }
END;  { PROCEDURE READ_BEGNODE }

PROCEDURE READ_LEVEL( VAR RIVERUP, RIVERDW : RIVER;
NUMBER_SPECIES : INTEGER );
VAR  I, J, S : INTEGER;
BEGIN  { Read in the distributions of downstream and upstream
         river level modifiers}
   READLN( F, RIVERDW.MEAN, RIVERDW.STDV );
   FOR S := 1 TO NUMBER_SPECIES DO  BEGIN
      READLN( F, J );
      RIVERDW.FACTOR[S] := J;
      IF J <> 0 THEN  BEGIN
         FOR I := 1 TO J DO   READ( F, RIVERDW.TABLE[S,I] );
         READLN( F );
      END;
   END;   { End of FOR Loop S }
   READLN( F, RIVERUP.MEAN, RIVERUP.STDV );
   FOR S := 1 TO NUMBER_SPECIES DO  BEGIN
      READLN( F, J );
      RIVERUP.FACTOR[S] := J;
      IF J <> 0 THEN  BEGIN
         FOR I := 1 TO J DO   READ( F, RIVERUP.TABLE[S,I] );
         READLN( F );
      END;
   END;   { End of FOR Loop S }
   WRITELN('Finished inputting river levels');
END;  { PROCEDURE READ_LEVEL }

PROCEDURE READ_UPWELL (VAR UPWELLING : RIVER; NUMBER_SPECIES :
                        INTEGER );
VAR I, J, S, : INTEGER;
BEGIN { Read in the distributions for ocean environmental
        modifiers }
  FOR S := 1 TO NUMBER_SPECIES DO BEGIN
     READLN ( F, J );
     UPWELLING.FACTOR[S] := J;
     IF J <> 0 THEN BEGIN
        FOR I := 1 TO J DO   READ( F, UPWELLING.TABLE[S,I] );
        READLN( F );
```

```
      END;
    END;
    WRITELN('Finished inputting upwelling tables');
END; { PROCEDURE READ_UPWELL }

PROCEDURE READ_NEWSTOCK( VAR NEWSTOCK : STOCK; BEGNODE :
              NODEBEGIN; NUMBER_BEGNODE, NUMBER_SPECIES, LAG :
              INTEGER;VAR REPRO : SPAWN );
VAR  I, K, L, S : INTEGER;
BEGIN  { Read in the initial newstock (number of eggs) for
         each species for 'LAG' number of years }
   FOR L := 1 TO LAG DO BEGIN
       FOR I := 1 TO NUMBER_BEGNODE DO  BEGIN
           K := BEGNODE[I].LOCATE;
           FOR S := 1 TO NUMBER_SPECIES DO
               READ( F, NEWSTOCK[L,K].SPECIES[S] );
           READLN( F );
       END;  { End of FOR Loop I }
   END;  { End of FOR Loop L }
     FOR S := 1 TO NUMBER_SPECIES DO
       READLN( F, REPRO[S].ECON, REPRO[S].EMULT,REPRO[S].MULT );
END;  { PROCEDURE READ_NEWSTOCK }

PROCEDURE READ_HOLDING
( VAR HOLDING : PATTERN; NUMBER_SPECIES, LAG, PERIOD : INTEGER );
VAR  I, L, S : INTEGER;
           A : REAL;
BEGIN  { Read in the number of fish existing at the beginning of
        the run in the ocean delay periods for each species }
   FOR I := 1 TO NUMBER_SPECIES DO  BEGIN
       FOR S := 0 TO PERIOD DO  BEGIN
           FOR L := 1 TO PERIOD DO  BEGIN
               READ( F, A );
               HOLDING[S,L].SPECIES[I] := A;
           END;
           READLN( F );
       END;
   END;
END;  { PROCEDURE READ_HOLDING }

PROCEDURE INITIALIZE ( VAR ENTER : TREE; VAR HARVESTED : FIELD;
      NUMBER_SPECIES, NUMBER_HARVEST, NUMBER_NODE : INTEGER );
VAR  I, S : INTEGER;
BEGIN  { Initialization }
   FOR S := 1 TO NUMBER_SPECIES DO BEGIN
       FOR I := 1 TO NUMBER_NODE    DO  ENTER[S,I]     := 0.0;
       FOR I := 1 TO NUMBER_HARVEST DO  HARVESTED[S,I] := 0.0;
```

```
   END;  { End of FOR Loop S }
END;   { PROCEDURE INITIALIZE }

PROCEDURE SORT_ORDER ( VAR ORDER : POINTER; NODE : INFORMATION;
                       NUMBER_NODE : INTEGER );
VAR  I, K, S : INTEGER;
BEGIN  { Sorting the nodes in order }
   FOR S := 1 TO NUMBER_NODE DO  ORDER[S] := S;
   FOR S := 1 TO NUMBER_NODE - 1 DO
       FOR I := S TO NUMBER_NODE DO
           IF NODE[S].ORDER > NODE[I].ORDER THEN BEGIN
                         K := NODE[S].ORDER;
              NODE[S].ORDER := NODE[I].ORDER;
              NODE[I].ORDER := K;
                         K := ORDER[S];
                   ORDER[S] := ORDER[I];
                   ORDER[I] := K;
           END;
END;   { PROCEDURE SORT_ORDER }

{   The following numbers MULTIPLIER, INCREMENT, and MODULUS   }
{   are choosen such that the overflow will not occur for a 32 }
{   bits machine.  These three numbers are suggested by        }
{   Jerrold L. Wagener, 1980, "FORTRAN 77 Principles of        }
{   Programming", John Wiley & Sons, Chapter 8, page 177 - 176.}

FUNCTION RANDOM : REAL;
CONST    MULTIPLIER = 1029;
         INCREMENT  = 221591;
         MODULUS    = 1048576;
VAR      SEEDRAND : INTEGER4;
BEGIN  { Generation of Random Number }
   SEEDRAND := ( RANDSEED * MULTIPLIER + INCREMENT ) MOD MODULUS;
   RANDSEED := SEEDRAND;
   RANDOM   := RANDSEED / MODULUS;
END;   { FUNCTION RANDOM }

FUNCTION NORMAL_RANDOM_GNTR( MEAN, STDV : REAL ) : REAL;
CONST  RAD = 57.29578;
VAR    RDN1, RDN2 : REAL;
BEGIN  { Normal Random Number Generator }
   RDN1 := RANDOM;
   IF RDN1 <= 0.0 THEN RDN1 := 1.0 / MAXINT;
   RDN2 := RANDOM * RAD;
   RDN1 := SQRT( -2.0 * LN( RDN1 ) );
   RDN2 := COS( RDN2 );
   NORMAL_RANDOM_GNTR := RDN1 * RDN2 * STDV + MEAN;
```

```
END;   { FUNCTION NORMAL_RANDOM_GNTR }

FUNCTION RATE_CALCULATION( STOCH : PROJECT; S, I : INTEGER ) :
                           REAL;
VAR    A, B, RATE : REAL;  J : INTEGER;
BEGIN  { Calculates the Stochastic Passage Rate or Harvest Rate
         using information on distribution type and specs  }
   J := STOCH[S].DISTRIBUTION;
   IF J = { Uniform Distribution } 0 THEN  BEGIN
      A := STOCH[S].PH_RATE[I,1]; { Minimum }
      B := STOCH[S].PH_RATE[I,2]; { Range   }
      RATE := B * RANDOM + A;              END
   ELSE IF J = { Normal Distribution } 1 THEN  BEGIN
           A := STOCH[S].PH_RATE[I,1]; { Mean     }
           B := STOCH[S].PH_RATE[I,2]; { St. Dev. }
           RATE := NORMAL_RANDOM_GNTR( A, B );
           IF RATE < 0.0 THEN
              RATE := 0.0
           ELSE IF RATE > 1.0 THEN
                   RATE := 1.0;
         { END IF }
    END; { END IF }
   RATE_CALCULATION := RATE;
END;  { FUNCTION RATE_CALCULATION }


PROCEDURE INITIAL_BEGNODE ( VAR ENTER : TREE; BEGNODE :
          NODEBEGIN; NEWSTOCK : STOCK; NUMBER_BEGNODE,
          NUMBER_SPECIES, L : INTEGER; REPRO : SPAWN; YEAR
          :INTEGER );
VAR           I, K, S : INTEGER;
        FISH, EGGS, A : REAL;
BEGIN  { Calculate the number of fish for the beginning nodes }
   FOR S := 1 TO NUMBER_BEGNODE DO BEGIN
       K := BEGNODE[S].LOCATE;
       FOR I := 1 TO NUMBER_SPECIES DO BEGIN
           EGGS := NEWSTOCK[L,K].SPECIES[I];
           IF EGGS > BEGNODE[S].MAXEGGS[I] THEN  EGGS :=
      BEGNODE[S].MAXEGGS[I];
           IF EGGS < BEGNODE[S].MINEGGS[I] THEN EGGS :=
     BEGNODE[S].MINEGGS[I];
           IF BEGNODE[S].SMOLTSF[I] >= YEAR THEN EGGS :=
               NEWSTOCK[1,K].SPECIES[I];
           A:= REPRO[I].EMULT * LN( EGGS );
           A:= A + REPRO[I].ECON;
           FISH := EXP( A ) * REPRO[I].MULT;
           ENTER[I,K] := FISH;
```

```
      END;  { FOR I }
   END;  { FOR S }
END;   { PROCEDURE INITIAL_BEGNODE }

PROCEDURE RIVER_LEVEL ( VAR LEVEL : PASSRATE; RVRLVL : RIVER;
                        NUMBER_SPECIES : INTEGER );
VAR  I, K, S : INTEGER;
     NUMBER : REAL;
BEGIN  { Compute the river level modifier }

  NUMBER := NORMAL_RANDOM_GNTR( UPWELLING.MEAN, UPWELLING.STDV );

   I := TRUNC( NUMBER * 10) + 1;
       IF  I > 10 THEN  I := 10 ;
       IF  I < 1  THEN  I := 1  ;

   FOR S := 1 TO NUMBER_SPECIES DO BEGIN
       K := RVRLVL.FACTOR[S];
       IF K = 0 THEN
          LEVEL[S] := 1
       ELSE  BEGIN
          LEVEL[S] := RVRLVL.TABLE[S,I];
       END;
   END;  { FOR S }
END;   { PROCEDURE RIVER_LEVEL }

PROCEDURE FISH_OUT ( VAR ENTER, LEAVE : TREE; FLAGPH : FLAG;
                     STOCH : PROJECT; LEVEL : PASSRATE; NODE :
                     INFORMATION; NUMBER_SPECIES, K : INTEGER );
VAR    I, S : INTEGER;  PASSAGE : REAL;
BEGIN  { Compute the number of fish available for harvest at a
         node, i.e. (passage rate x number of fish entering the
         node) }
   FOR I := 1 TO NUMBER_SPECIES DO  BEGIN
       S := NODE[K].STPR[I];
       IF S < 0 { i.e. Not Stochastic } THEN
          PASSAGE := FLAGPH[I].PASSAGE[K]
       ELSE  { i.e. It is Stochastic }
          PASSAGE := RATE_CALCULATION( STOCH, K, I );
       S := NODE[K].BEFLAG;
       IF ( S <> 1 ) AND ( S <> 3 ) AND ( S <> 4 ) THEN
          PASSAGE := PASSAGE * LEVEL[I];
       IF PASSAGE <= 1.0 THEN
           LEAVE[I,K] := ENTER[I,K] * PASSAGE;
       IF PASSAGE >  1.0 THEN  LEAVE[I,K] := ENTER[I,K] * 1.0;
   END;  { FOR I }
END;   { PROCEDURE FISH_OUT }
```

```
PROCEDURE FISH_HARVESTED ( VAR HARVESTED : FIELD; VAR LEAVE :
   TREE; NODE : INFORMATION; STOCH : PROJECT; FLAGPH : FLAG;
   NUMBER_SPECIES,  J, K, YEAR : INTEGER );
CONST  YES  = 0;  NO = 1;
VAR        CATCH, I, L, M, S          : INTEGER;
  AMOUNT, HARATE, HRATE,YRMIN,FILL  : REAL;
                         RATE        : ARRAY[1..3] OF REAL;
BEGIN  { Compute the number of fish that are harvested }
   M := NODE[K].PARTIES;
   IF M <> 0 THEN BEGIN
     YRMIN := NODE[K].MINFISH[0];
      FOR I := 1 TO NUMBER_SPECIES DO  BEGIN
          CATCH  := NO;
          HARATE := 0.0;
          AMOUNT := NODE[K].MINFISH[I];
          IF ( AMOUNT < 0.0 ) OR ( LEAVE[I,K] > AMOUNT ) OR
           (YRMIN < YEAR) THEN BEGIN
             FOR L := 1 TO M DO  BEGIN
                 N := NODE[K].PWHRST[L,I];
                 IF N < 0 { i.e. Not Stochastic } THEN
                    RATE[L] := FLAGPH[I].PDHR[K,L]
                 ELSE     { i.e. It is Stochastic }
                    RATE[L] := RATE_CALCULATION( STOCH, K, I );
            IF (NODE[K].HFLAG[L] > 0) AND
               (NODE[K].HFLAG[L] >= YEAR) THEN
                       RATE[L] := FLAGPH[I].SPECIAL[K,L];
                 HARATE := HARATE + RATE[L];
             END;  { FOR L }
             IF HARATE > 1.0 THEN  BEGIN
                FOR L := 1 TO M DO
                    RATE[L] := RATE[L] / HARATE;
                    HARATE := 1.0;
                    END;
                    CATCH := YES;
           END;
             IF CATCH = NO THEN
                FILL := RATE_CALCULATION( STOCH, K, I);
             IF (AMOUNT < 0.0) OR (YRMIN < YEAR) THEN
                HARATE := 1.0 - HARATE
             ELSE IF LEAVE[I,K] > AMOUNT THEN  BEGIN
                HRATE := ( LEAVE[I,K] - AMOUNT ) / LEAVE[I,K];
                IF HARATE < HRATE THEN
                   HARATE := 1.0 - HARATE
                ELSE  BEGIN
                   AMOUNT := HRATE / HARATE;
                   HARATE := 1.0 - HRATE;
```

```
                    FOR L := 1 TO M DO
                       RATE[L] := RATE[L] * AMOUNT;
                 END;
              END;  { End If }
           IF CATCH = YES THEN  BEGIN
              FOR L := 1 TO M DO  BEGIN
                  S := NODE[K].PWHR[L];
                  HARVESTED[I,S] := HARVESTED[I,S] + LEAVE[I,K] *
                    RATE[L];
              END;
              LEAVE[I,K] := LEAVE[I,K] * HARATE;
           END;
            IF K = 13 THEN WRITELN( G, LEAVE[I,K]: 10:2 );
            IF K = 8  THEN WRITELN( G, LEAVE[I,K]: 15:2 );
        END;  { FOR I }
    END; { IF }
END;   { PROCEDURE FISH_HARVESTED }

PROCEDURE FISH_SPLIT
( VAR ENTER, LEAVE : TREE; NODE : INFORMATION; NUMBER_SPECIES, K
: INTEGER );
VAR  I, J, N, S : INTEGER;
        SPLIT, SUM : REAL;

BEGIN  { Compute the split factor for the fish returning through
         node branches}
   FOR I := 1 TO NUMBER_SPECIES DO BEGIN
       SUM := 0.0;
       FOR J := 1 TO NODE[K].NEXT DO BEGIN
           S := NODE[K].SPLIT[J];
           SUM := SUM + ENTER[I,S];
       END;  { End of FOR Loop J }
       IF SUM = 0.0 THEN  SUM := 1.0;
       FOR J := 1 TO NODE[K].NEXT DO BEGIN
           N := NODE[K].BRANCH[J];
           S := NODE[K].SPLIT[J];
           SPLIT := ENTER[I,S] / SUM;
           ENTER[I,N] := ENTER[I,N] + LEAVE[I,K] * SPLIT;
       END;  { FOR J }
   END;  { FOR I }
END;   { PROCEDURE FISH_SPLIT }

PROCEDURE UPWFAC_GEN ( VAR UPWELLING : RIVER; VAR UPWFAC :
                       PASSRATE );
VAR I, J, S : INTEGER;
    NUMBER : REAL;
BEGIN { Calculation of the Ocean Environmental Modifier }
```

```
  NUMBER := NORMAL_RANDOM_GNTR( UPWELLING.MEAN, UPWELLING.STDV );

     I := TRUNC( NUMBER * 10) + 1;
        IF  I > 10 THEN  I := 10 ;
        IF  I < 1  THEN  I := 1  ;
     FOR S := 1 TO NUMBER_SPECIES DO
       UPWFAC[S] := UPWELLING.TABLE[S,I];
END; {  PROCEDURE UPWFAC_GEN }

PROCEDURE DETER_DELAY ( VAR DELAY : LAGYEAR; VAR SPECIES : FISHS;
                   S, PERIOD : INTEGER; VAR UPWFAC : PASSRATE );

VAR    I, L, J : INTEGER;
BEGIN  { Calculate and assign the number of fish remaining in the
         ocean for additional cycles to the appropriate delay
         module }
   IF SPECIES[S].STH = 1 { i.e. use the defined delay % } THEN
      FOR L := 0 TO PERIOD DO  DELAY[L] := SPECIES[S].DELAY[L]
   ELSE  BEGIN  { i.e. use the  delay % MODIFIED BY UPWELLING }
      FOR L := 0 TO PERIOD DO  DELAY[L] := 0.0;
          DELAY[0] := SPECIES[S].DELAY[0] / UPWFAC[S];
          DELAY[1] := SPECIES[S].DELAY[1] / UPWFAC[S];
          DELAY[3] := SPECIES[S].DELAY[3] * UPWFAC[S];
          DELAY[2] := 1 - (DELAY[0]+DELAY[1]+DELAY[3]);
      IF UPWFAC[S] > 1.0 THEN BEGIN
      FOR I := 0 TO 3 DO
          DELAY[I] := DELAY[I] * SQRT( UPWFAC[S]);
      END; {if}
      IF UPWFAC[S] < 1.0 THEN BEGIN
        FOR I := 0 TO 3 DO
          DELAY[I] := DELAY[I] * SQRT( SQRT( UPWFAC[S]));
      END; {if}
   END; { else }
      FOR L := 0 TO PERIOD DO SPECIES[S].RELAY[L] := DELAY[L];
END;  { PROCEDURE DETER_DELAY }

PROCEDURE FISH_GROUP ( VAR ENTER, LEAVE : TREE; VAR HOLDING :
          PATTERN; VAR SPECIES : FISHS; NUMBER_SPECIES, J, K,
          PTLAG, PERIOD : INTEGER;VAR UPWFAC : PASSRATE );
VAR    I, L, N, S : INTEGER;  DELAY : LAGYEAR;
BEGIN  { Compute the fish returning to the main flow of the model
         from the delay modules }
   FOR S := 1 TO NUMBER_SPECIES DO  BEGIN

       DETER_DELAY( DELAY, SPECIES, S, PERIOD, UPWFAC );
       ENTER[S,J] := ENTER[S,J] + LEAVE[S,K] * DELAY[0];
       L := PTLAG;
```

```
      FOR I := 1 TO PERIOD DO  BEGIN
          HOLDING[L,I].SPECIES[S] := LEAVE[S,K] * DELAY[I];
          L := L + 1;
          IF  L > PERIOD  THEN  L := 0;
      END;  { FOR I }
   END;  { FOR S }
END;   { PROCEDURE FISH_GROUP }

PROCEDURE FISH_BACK ( VAR ENTER : TREE; VAR FISHAGE : AGE;
          HOLDING : PATTERN; NODE : INFORMATION; NUMBER_SPECIES,
          J, K, PERIOD, PTOUT : INTEGER );
VAR   L, S : INTEGER;  SUM : REAL;
BEGIN  { Compute the age composition of fish returning to the
         model mainstem }
   N := PTOUT;
   FOR S := 1 TO NUMBER_SPECIES DO  BEGIN
       SUM := ENTER[S,J];
       FOR L := 1 TO PERIOD DO  BEGIN
           FISHAGE[L,S] := HOLDING[N,L].SPECIES[S];
                   SUM  := SUM + FISHAGE[L,S];
       END;
       FISHAGE[0,S] := ENTER[S,J];
         ENTER[S,J] := SUM;
       FOR L := 0 TO PERIOD DO
           FISHAGE[L,S] := FISHAGE[L,S] / SUM;
   END;  { FOR S }
END;   { PROCEDURE FISH_BACK }

PROCEDURE FISH_RETURN( VAR NEWSTOCK : STOCK; ENDNODE : NODEND;
                     LEAVE : TREE; NUMBER_ENDNODE, NUMBER_SPECIES,
                     L,PERIOD : INTEGER; FISHAGE : AGE );
VAR    I, J, K, S, P : INTEGER;
       SUM : REAL;
BEGIN  { Calculating the number of eggs produced by the returning
         spawners }
   FOR S := 1 TO NUMBER_ENDNODE DO BEGIN
       J := ENDNODE[S].BEGNODE;
       K := ENDNODE[S].LOCATE;
       FOR I := 1 TO NUMBER_SPECIES DO BEGIN
           SUM := 0.0;
           FOR P := 0 TO PERIOD DO
              SUM := SUM + (FISHAGE[P,I] *
                               ENDNODE[S].FEMALE[I,P]);
           NEWSTOCK[L,J].SPECIES[I] := LEAVE[I,K] * SUM ;
       END; { FOR I }
   END;  { FOR S }
END;   { PROCEDURE FISH_RETURN }
```

```
PROCEDURE PRINT_HEADING( NUMBER_SPECIES, NUMBER_HARVEST,
NUMBER_NODE, NUMBER_BEGNODE, NUMBER_ENDNODE : INTEGER; NODE
: INFORMATION; BEGNODE : NODEBEGIN; ENDNODE : NODEND;
SPECIES : FISHS; HARVESTER : PARTIES );
BEGIN  { Print Heading for optional diagnostic printout }
   WRITELN( 'Start printing heading. . .' );
   WRITELN( G, ' The total stations ( nodes ) are ',
NUMBER_NODE:3, ' .' );
   WRITELN( G, ' There are ', NUMBER_BEGNODE:2, ' beginning
      stations.' );
   FOR I := 1 TO NUMBER_BEGNODE DO BEGIN
       J := BEGNODE[I].LOCATE;
    WRITELN( G, ' Station ', I:3, ' ', NODE[J].NAME, ' ( Node ',
            J:2, ' )' );
   END;  { End of FOR Loop I }
   WRITELN( G, ' There are ', NUMBER_ENDNODE:2, ' ending
   stations.' );
   FOR I := 1 TO NUMBER_ENDNODE DO BEGIN
       J := ENDNODE[I].LOCATE;
    WRITELN( G, ' Station ', I:3, ' ', NODE[J].NAME, ' ( Node ',
            J:2, ' )' );
   END;  { End of FOR Loop I }
   WRITELN( G, ' There are ', NUMBER_SPECIES:2, ' species.' );
   FOR I := 1 TO NUMBER_SPECIES DO
       WRITELN( G, ' ', I:3, ' ', SPECIES[I].NAME );
   WRITELN( G, ' There are ', NUMBER_HARVEST:2, ' harvesting
       parties.' );
   FOR I := 1 TO NUMBER_HARVEST DO
       WRITELN( G, ' ', I:3, ' ', HARVESTER[I] );
END;   { PROCEDURE PRINT_HEADING }

PROCEDURE PRINT_RESULT( ENTER, LEAVE : TREE;
FISHAGE : AGE; HARVESTED : FIELD; DSRL, LEVEL : PASSRATE;
NUMBER_SPECIES, NUMBER_HARVEST, NUMBER_NODE, GATE, PERIOD :
INTEGER );
VAR  I, S : INTEGER;
BEGIN  { Print Results by cycle in optional diagnostic printout }

   WRITELN( G, ' The rivier level factors for each species' );
   WRITELN( G, ' (factor=1, implies possible no river level
      distribution)' );
   WRITELN( G, ' Down Stream:');
   FOR S := 1 TO NUMBER_SPECIES DO
       WRITE( G, ' ', DSRL[S]:5:2 );   WRITELN( G );
   WRITELN( G, '   Up Stream:' );
   FOR S := 1 TO NUMBER_SPECIES DO
```

```
      WRITE( G, ' ', LEVEL[S]:5:2 );  WRITELN( G );
   WRITELN( G, ' Entering nodes:' );   WRITELN( G );
   FOR I := 1 TO NUMBER_NODE DO BEGIN
      FOR S := 1 TO NUMBER_SPECIES DO
         WRITE( G, ' ', ENTER[S,I]:10:2 );
      WRITELN( G );
   END;  { FOR I }
   WRITELN( G );
   WRITELN( G, ' Leaving nodes:' ); WRITELN( G );
   FOR I := 1 TO NUMBER_NODE DO BEGIN
      FOR S := 1 TO NUMBER_SPECIES DO
         WRITE( G, ' ', LEAVE[S,I]:10:2 );
      WRITELN( G );
   END;  { FOR I }
   WRITELN( G );
   WRITELN( G, ' Species grouped by age from 1 to ', PERIOD:1, '
         year old.' );
   WRITELN( G, ' Their persentage are ( started from node ',
      GATE:2, ' ):' );
   FOR I := 0 TO PERIOD DO  BEGIN
      FOR S := 1 TO NUMBER_SPECIES DO
         WRITE( G, ' ', FISHAGE[I,S]*100.0:10:2 );
      WRITELN( G );
   END;  { FOR I }
   WRITELN( G );
   WRITELN( G, ' Harvesting Table:' ); WRITELN( G );
   FOR I := 1 TO NUMBER_HARVEST DO BEGIN
      FOR S := 1 TO NUMBER_SPECIES DO
         WRITE( G, ' ', HARVESTED[S,I]:10:2 );
      WRITELN( G );
   END;  { FOR I }
   WRITELN( G );
END;   { PROCEDURE PRINT_RESULT }

PROCEDURE PRINT_HOLDING( VAR HOLDING : PATTERN ; SPECIES : FISHS;
                       PTOUT, PERIOD, NUMBER_SPECIES : INTEGER );
VAR       I, J, N, S : INTEGER;
BEGIN  { Print the delayed fish table by cycle for optional
         printout }
   WRITELN( G, ' Holding Period Percentage Rate for Each
            Species:' );
   FOR S := 1 TO NUMBER_SPECIES DO  BEGIN
      WRITE( G, ' ', S:1 );
      FOR I := 0 TO PERIOD DO WRITE( G, ' ',
            SPECIES[S].RELAY[I]:10:2 );
      WRITELN( G );
   END;
```

```
   WRITELN( G );
   WRITELN( G, ' Holding Period Table:   Holding Period ',
            PERIOD:2 );
   N := PTOUT - 1;
   IF  N < 0  THEN  N := PERIOD;
   FOR I := 1 TO PERIOD DO  BEGIN
      FOR S := 1 TO NUMBER_SPECIES DO BEGIN
         WRITE( G, ' ', HOLDING[N,I].SPECIES[S]:10:2 );
         HOLDING[N,I].SPECIES[S] := 0.0;
      END;  { FOR S }
      WRITELN( G, '  < Prd 0 ', N:1 );
   END;
   WRITELN( G );
   FOR I := 1 TO PERIOD DO  BEGIN
      N := N + 1;
      IF  N > PERIOD  THEN  N := 0;
      FOR J := I TO PERIOD DO  BEGIN
         FOR S := 1 TO NUMBER_SPECIES DO
            WRITE( G, ' ', HOLDING[N,J].SPECIES[S]:10:2 );
         WRITELN( G, '  < Prd ', I:1, N:2 );
      END;
   END;  { FOR I }
   WRITELN( G );
END;   { PROCEDURE PRINT_HOLDING }

PROCEDURE PRINT_DOLLAR ( HARVESTED : FIELD; FISHAGE : AGE;
          NUMBER_SPECIES, NUMBER_HARVEST, PERIOD : INTEGER;
          HARVESTYR : YRHARVEST; SPECIES : FISHS; VAR DOLSTRM :
          HARVAL; YEAR : INTEGER; VAR TOTLBS : FIELD );
VAR  I, J, S, Z : INTEGER;  SUM, WEIGHT, LBS  : REAL;
     COL  : ARRAY [1..MAX_SPECIES] OF REAL;
     ROW  : ARRAY [1..MAX_HARVEST] OF REAL;
BEGIN  { Compute the dollar value of the harvest }
   Z := YEAR;
   FOR I := 1 TO NUMBER_HARVEST DO  BEGIN
      ROW[I] := 0.0;
      FOR S := 1 TO NUMBER_SPECIES DO  BEGIN
            SUM := HARVESTED[S,I];
         WEIGHT := 0.0;
          LBS    := 0.0;
         FOR J := 0 TO PERIOD DO
         WEIGHT := WEIGHT + SUM * FISHAGE[J,S] *
                   SPECIES[S].WTYR[J,I] *
                   HARVESTYR[S].FISHVALUE[I,J];
         HARVESTED[S,I] := WEIGHT ;
          FOR J := 0 TO PERIOD DO
```

```
            LBS := LBS + SUM * FISHAGE[J,S] *
                   SPECIES[S].WTYR[J,I];
            TOTLBS[S,I] := TOTLBS[S,I] + LBS;
             ROW[I] := ROW[I] + HARVESTED[S,I];
        END;  { End of FOR Loop S }
    END;  { End of FOR Loop I }
    SUM := 0.0;
    FOR J := 1 TO NUMBER_SPECIES DO  BEGIN
        COL[J] := 0.0;
        FOR I := 1 TO NUMBER_HARVEST DO  COL[J] := COL[J] +
                 HARVESTED[J,I];
        SUM := SUM + COL[J];
    END;  { End of FOR Loop I }
 {  WRITELN( G, ' Harvesting Table in terms of dollars:' );}
 {  WRITELN( G );}
    FOR I:= 1 TO NUMBER_HARVEST DO BEGIN
           FOR J := 1 TO NUMBER_SPECIES DO
           DOLSTRM[J,I,Z] := HARVESTED[J,I];
 {           WRITE( G, ' ', HARVESTED[J,I]:10:2 );}
 {       WRITELN( G, ' ', ROW[I]:10:2 );}
 { WRITELN( DOLSTRM[I,Z] :14:2, ROW[I] );}
    END;  { End of FOR Loop I }
 {  FOR J := 1 TO NUMBER_SPECIES DO
      WRITE( G, ' ', COL[J]:10:2 );}
 {  WRITELN( G, ' ', SUM:10:2 );}
END;  { PROCEDURE PRINT_DOLLAR }

PROCEDURE NUMFISH_TOTAL( VAR HARVESTED : FIELD; VAR FISHTOT :
             PASSRATE; VAR SUMTOT : FIELD;NUMBER_SPECIES,
             NUMBER_HARVEST : INTEGER; VAR  HARVTOT : DISVAL );
VAR S, I : INTEGER;

BEGIN {Cumputing the number of fish harvested by each party }
{   WRITELN( G, '          CURRENT HARVEST  -  TOTAL HARVEST');}
   FOR S := 1 TO NUMBER_SPECIES DO BEGIN
          FISHTOT[S] := 0.0;
      FOR I := 1 TO NUMBER_HARVEST DO BEGIN
          SUMTOT[S,I] := SUMTOT[S,I] + HARVESTED[S,I];
           FISHTOT[S] := FISHTOT[S] + SUMTOT[S,I];
          END; {FOR I}
 {     WRITELN( G,'SPECIES',S :3, SUMTOT[S] :10:2, FISHTOT[S]
                :14:2);}
   END; {for S}
     FOR I := 1 TO NUMBER_HARVEST DO BEGIN
          HARVTOT[I] := 0.0;
          FOR S := 1 TO NUMBER_SPECIES DO
          HARVTOT[I] := HARVTOT[I] + SUMTOT[S,I];
```

```
     END; {FOR I}
END; { PROCEDURE NUMFISH_TOTAL }

PROCEDURE DISCOUNT_VALUES(VAR DISRATE : REAL; DOLSTRM : HARVAL;
          DISTREAM : FIELD; YEAR,NUMBER_HARVEST,NUMBER_SPECIES :
          INTEGER; SUMTOT : FIELD;FISHTOT : PASSRATE; HARVTOT :
          DISVAL );
VAR I, J, Z : INTEGER; TOTAL, RATE, K,A,B : REAL;
      PARTYNPV : ARRAY [1..MAX_HARVEST] OF REAL;
          SPECNPV  : ARRAY [1..MAX_SPECIES] OF REAL;
BEGIN  { Compute the discounted value of harvest and print
         summary }
   TOTAL := 0.0;
   FOR I := 1 TO NUMBER_HARVEST DO BEGIN
          PARTYNPV[I] := 0.0;
          FOR J := 1 TO NUMBER_SPECIES DO BEGIN
          DISTREAM[J,I] := 0.0;
          FOR Z := 1 TO YEAR DO BEGIN
           A := LN( DISRATE );
              B := Z * A;
          RATE := EXP( B );
             DOLSTRM[J,I,Z] := DOLSTRM[J,I,Z] / RATE ;
           DISTREAM[J,I] := DISTREAM[J,I] + DOLSTRM[J,I,Z];
           END; { for Z }
          TOTAL := TOTAL + DISTREAM[J,I];
          PARTYNPV[I] := PARTYNPV[I] + DISTREAM[J,I];
        END; { for J }
          WRITE( H, PARTYNPV[I] :12:0);
     END; {FOR I}
   WRITELN( H,' NPV by Party' );
     FOR J := 1 TO NUMBER_SPECIES DO BEGIN
          SPECNPV[J] := 0.0;
          FOR I := 1 TO NUMBER_HARVEST DO
          SPECNPV[J] := SPECNPV[J] + DISTREAM[J,I];
          WRITE( H, SPECNPV[J] :12:0);
     END; {FOR J}
     WRITELN( H, ' NPV by Species');
   WRITELN( H, TOTAL : 14:0, ' IS THE TOTAL DISCOUNTED VALUE ');

     FOR I := 1 TO NUMBER_HARVEST DO BEGIN
          FOR J := 1 TO NUMBER_SPECIES DO
          WRITE( H, SUMTOT[J,I] : 12:1);
          WRITELN( H, HARVTOT[I] : 12:1,' fish H by party');
     END; {FOR I}
     FOR J := 1 TO NUMBER_SPECIES DO
          WRITE( H, FISHTOT[J] : 12:1);
     WRITELN( H,' species totals');
```

```
END; { PROCEDURE DISCOUNT_VALUES }


BEGIN  {  Main Program  }
{
   Set up the input and output files.
}
     WRITE ('DO YOU WISH TO ENTER I/O FILE NAMES THROUGH A
SEPARATE            FILE?:');
     READLN (ANSWER2);
     IF ANSWER2 = 'Y' THEN BEGIN
          WRITE ('ENTER NAME OF FILE CONTAINING RUN-FILE
NAMES:');
          READLN (IN2NAME);
          ASSIGN (E,IN2NAME);
          RESET ( E );
          READLN (E,FILES);
     END;

     IF ANSWER2 <> 'Y' THEN BEGIN
        FILES := 1;
    WRITE  ( 'Enter the input file name: ' );
    READLN ( INPUTNAME );
        ASSIGN ( F, INPUTNAME );
        RESET  ( F );
        WRITE  ( 'Enter name of the diagnostic output file: ' );
        READLN ( OUTPUTNAME );
        ASSIGN ( G, OUTPUTNAME );
        WRITE  ( 'Enter name of summary output file: ');
        READLN ( OUT2NAME );
        ASSIGN ( H, OUT2NAME );
        REWRITE( H );
        REWRITE( G );
     END;
FOR Z:= 1 TO FILES DO BEGIN
     IF ANSWER2 = 'Y' THEN BEGIN
          READLN (E,INPUTNAME,OUTPUTNAME,OUT2NAME);
          ASSIGN(F,INPUTNAME);
          ASSIGN(G,OUTPUTNAME);
          ASSIGN(H,OUT2NAME);
          RESET(F);
          REWRITE(G);
          REWRITE(H);
     END;
{
   Read in the Number of Runs for Simulation and the Random Seed.
}
```

```
 READLN ( F, NUMBER_RUNS );
     READLN ( F, RANDSEED );

FOR U := 1 TO NUMBER_RUNS DO BEGIN

     RESET  ( F );
     READLN ( F );
     READLN ( F );

 READLN ( F, NUMBER_YEAR );
 READLN ( F, LAG, PERIOD );
 READLN ( F, DISRATE );
{
   Read in the data for species.
}
 READLN ( F, NUMBER_SPECIES );
     READLN ( F, NUMBER_HARVEST );
 FOR S := 1 TO NUMBER_SPECIES DO BEGIN
       READLN( F, SPECIES[S].NAME );
       READLN( F, SPECIES[S].STH  );
      FOR J := 0 TO PERIOD DO  READ ( F, SPECIES[S].DELAY[J] );
      READLN( F );
           FOR J := 0 TO PERIOD DO BEGIN
           FOR I := 1 TO NUMBER_HARVEST DO
           READ( F, SPECIES[S].WTYR[J,I] );
            READLN( F );
           END; {FOR J}
 END; {FOR S}
   WRITELN( 'Finish reading the data for species.',
            '  #_species = ', NUMBER_SPECIES:3 );
{
   Read in the data of harvesting party and fish prices.
}

   FOR S := 1 TO NUMBER_HARVEST DO  READLN( F, HARVESTER[S] );
   WRITELN( 'Finish reading the data of harvesting party.',
            '  #_Harvesting Parties = ', NUMBER_HARVEST:3 );
   READ_PRICES( HARVESTYR, NUMBER_SPECIES, NUMBER_HARVEST,
                LAG,PERIOD );
   WRITELN( 'Finish reading the data of fish prices.' );
{
   Read in data for nodes.
}
   READ_NODES( NUMBER_NODE, NUMBER_SPECIES, GATE, NODE,  FLAGPH,
               STOCHP, STOCHH );
   WRITELN( 'Finish reading the data of nodes.   #_Node = ',
           NUMBER_NODE:3 );
```

```
{
  Read in the beginning and ending nodes information.
}
  READLN( F, NUMBER_BEGNODE );
  READ_BEGNODE( BEGNODE, NUMBER_SPECIES, NUMBER_BEGNODE );
  WRITELN( 'Finish reading the data of beginning nodes.',
           '   #_Begnode = ', NUMBER_BEGNODE:3 );
  READLN( F, NUMBER_ENDNODE );
  FOR S := 1 TO NUMBER_ENDNODE DO BEGIN
      READLN( F, ENDNODE[S].LOCATE  );
      READLN( F, ENDNODE[S].BEGNODE );
      FOR I := 1 TO NUMBER_SPECIES DO BEGIN
          FOR K := 0 TO PERIOD DO
          READ( F, ENDNODE[S].FEMALE[I,K] );
          READLN(F);
      END; { FOR I}
  END;  { FOR S }
  WRITELN( 'Finish reading the data of ending nodes.',
           '  #_Ending node = ', NUMBER_ENDNODE:3 );
{
  Read in the River Level Distributions.
}
  READ_LEVEL( RIVERUP, RIVERDW, NUMBER_SPECIES );

  WRITELN( 'Finish reading the data of river level
           distributions.' );
{
  Read in the Upwelling Table.
}
  READLN( F, ANSWER);
  IF ANSWER = YES { i.e. use upwelling tables } THEN BEGIN
      READLN( F, UPWELLING.MEAN, UPWELLING.STDV);
      READ_UPWELL( UPWELLING , NUMBER_SPECIES);
  END; {if}
{
  Read in the newstock and the delay percentages.
}
  READ_NEWSTOCK( NEWSTOCK, BEGNODE, NUMBER_BEGNODE,
                 NUMBER_SPECIES, LAG, REPRO );
  WRITELN( 'Finish reading the data of newstock.' );
  PTOUT := 0;
  PTLAG := 1;
  READ_HOLDING( HOLDING, NUMBER_SPECIES, LAG, PERIOD );
  WRITELN( 'Finish reading the data of holding fishs for the lag
           years.' );
{
  Print the Heading.
```

```
}
 {  PRINT_HEADING( NUMBER_SPECIES, NUMBER_HARVEST,}
 {                 NUMBER_NODE, NUMBER_BEGNODE, NUMBER_ENDNODE,}
 {                 NODE, BEGNODEW, ENDNODE, SPECIES, HARVESTER );}
 {  WRITELN( 'Finish printing the heading. . .' );              }

{
   Starting the simulation.
}
   L := 0;
   SORT_ORDER( ORDER, NODE, NUMBER_NODE );
   WRITELN( 'Starting the simulation. . .' );

{
   Initialize Summary Variables
}
  FOR S := 1 TO NUMBER_SPECIES DO BEGIN
        FOR I := 1 TO NUMBER_HARVEST DO BEGIN
          TOTLBS[S,I] := 0.0;
          SUMTOT[S,I] := 0.0;
        END; {FOR I}
     END; {FOR S}
     ALLLBS := 0.0;

{
   Begin Yearly Cycles
}
   FOR YEAR := 1 TO NUMBER_YEAR DO BEGIN

   UPWFAC_GEN ( UPWELLING, UPWFAC );

   L := L + 1;
   IF  L > LAG  THEN  L := 1;
   INITIALIZE( ENTER, HARVEST, NUMBER_SPECIES, NUMBER_HARVEST,
               NUMBER_NODE );
   INITIAL_BEGNODE( ENTER, BEGNODE,NEWSTOCK, NUMBER_BEGNODE,
                    NUMBER_SPECIES,L,REPRO,YEAR );
   RIVER_LEVEL( LEVEL, RIVERDW, NUMBER_SPECIES );
{
   Computing the fish count before and after each node.
}
   FOR S := 1 TO NUMBER_NODE DO BEGIN
       K := ORDER[S];
       J := NODE[K].BRANCH[1];

           FISH_OUT( ENTER, LEAVE, FLAGPH, STOCHP,
                LEVEL, NODE, NUMBER_SPECIES, K );
```

```
      FISH_HARVESTED( HARVEST, LEAVE, NODE, STOCHH,
                          FLAGPH, NUMBER_SPECIES, J, K, YEAR );
      IF NODE[K].NEXT > 1 THEN BEGIN
         FISH_SPLIT( ENTER, LEAVE, NODE, NUMBER_SPECIES, K );
      END
      ELSE  BEGIN
         N := NODE[K].BEFLAG;
         IF  N = OUT  THEN  BEGIN
             FISH_GROUP( ENTER, LEAVE, HOLDING, SPECIES,
                         NUMBER_SPECIES, J, K, PTLAG, PERIOD,
                         UPWFAC );
             DSRL := LEVEL;
             RIVER_LEVEL( LEVEL, RIVERUP, NUMBER_SPECIES );
             FISH_BACK( ENTER, FISHAGE, HOLDING, NODE,
                        NUMBER_SPECIES, J, K, PERIOD, PTOUT );
             PTLAG := PTLAG + 1;
             PTOUT := PTOUT + 1;
             IF  PTLAG > PERIOD  THEN  PTLAG := 0;
             IF  PTOUT > PERIOD  THEN  PTOUT := 0;   END
         ELSE
             FOR I := 1 TO NUMBER_SPECIES DO BEGIN
                 ENTER[I,J] := LEAVE[I,K] + ENTER[I,J];
             END; { FOR I }
      END;
   END;  { FOR S }
{
   Print results.
}
 {  WRITELN( 'Printing the result. . .' );}
 {  WRITELN( G, ' The Result of Without Project.',}
 {          '   Year ', YEAR:3, '   Lag Year ', L:2 );}
 {  PRINT_RESULT( ENTER, LEAVE, FISHAGE, HARVEST, DSRL, LEVEL,}
 {                NUMBER_SPECIES, NUMBER_HARVEST, NUMBER_NODE,
                  GATE, PERIOD );}
 {  PRINT_HOLDING( HOLDING, SPECIES, PTOUT, PERIOD,
                   NUMBER_SPECIES );}
{
   Compute the Harvest Tables in term of dollars and print them.
}
   PRINT_DOLLAR( HARVEST, FISHAGE, NUMBER_SPECIES,NUMBER_HARVEST,
           PERIOD, HARVESTYR, SPECIES, DOLSTRM, YEAR, TOTLBS );

   NUMFISH_TOTAL( HARVEST, FISHTOT, SUMTOT, NUMBER_SPECIES,
                  NUMBER_HARVEST, HARVTOT );
{
   Calculating the Stock of New Eggs.
}
```

```
   WRITELN   ( 'Calculating the stock of new eggs. ',  );
   FISH_RETURN( NEWSTOCK, ENDNODE, LEAVE, NUMBER_ENDNODE,
                NUMBER_SPECIES, L, PERIOD, FISHAGE );
  {  WRITELN( G );  WRITELN(G);}
   END;  { End of FOR Loop YEAR }
{
   Calculate and output the discounted values
}
   DISCOUNT_VALUES( DISRATE, DOLSTRM, DISTREAM, YEAR,
      NUMBER_HARVEST, NUMBER_SPECIES, SUMTOT, FISHTOT, HARVTOT );
{
   Calculate and output the number of pounds harvested
}
 FOR I := 1 TO NUMBER_HARVEST DO BEGIN
        FOR N := 1 TO NUMBER_SPECIES DO BEGIN
          ALLLBS := ALLLBS + TOTLBS[N,I];
          WRITE( H, TOTLBS[N,I] : 13 : 2);
        END; {FOR N}
    WRITE( H, ' lbs. Party #', I : 2);
    WRITELN( H );
     END; {FOR I}
     WRITELN( H, ALLLBS : 16:2, ' Total lbs. of all species
              caught-RUN', U:3);

WRITELN( 'End of the simulation, run # ',U : 3,', ', INPUTNAME );

END; { FOR U }

{   Close the input and output files defined by user.}
 CLOSE( F );
 CLOSE( G );
     CLOSE( H );
END;{FOR Z}
     IF ANSWER2 = 'Y' THEN CLOSE( E );
END.   {  End of Program  }
```

APPENDIX B

Input File for the Baseline Case

```
50  Number of model runs
99999 Random Seed
30   Number of years for the simulation
2  3   Year Lags & Period
1.046
2  Number of Species
3  Number of Harvest parties
Hatchery Sp. Chinook
0     Use the Stochastic holding periods
0.08 .022 0.58 0.12  Delay %
 0.0     2.6    2.6   Weight at lag + 0 year
 6.75    6.8    6.8          at lag + 1 year
13.2    15.7   15.7          at lag + 2 years
16.25   22.0   22.0          at lag + 3 years
Wild Sp. Chinook
0     Use the Stochastic holding periods
0.09 0.22 0.50 0.19  Delay %
 0.0     2.6    2.6   Weight at lag + 0 year
 6.75    6.7    6.7          at lag + 1 year
13.2    15.5   15.5          at lag + 2 years
16.25   21.0   21.0          at lag + 3 years
Ocean Fishery
Lower/Middle River
Upper River         //       V-Age specific harvest prices-V
1.00  2.00  2.50  3.00  Species 1 ($/lb) for  Harvest Party  1
7.33  7.33  7.33  7.33  Species 1 ($/lb) for  Harvest Party  2
7.33  7.33  7.33  7.33  Species 1 ($/lb) for  Harvest Party  3
1.00  2.00  2.50  3.00  Species 2 ($/lb) for  Harvest Party  1
7.33  7.33  7.33  7.33  Species 2 ($/lb) for  Harvest Party  2
7.33  7.33  7.33  7.33  Species 2 ($/lb) for  Harvest Party  3
14  8     Number of Nodes /  Gate Number ( fish coming back )
Hatchery/Spawning            Node 1
0  Order
1  Number of Branches
2  is the node will be going to
1   Stochastic  ( Passage Rate )
0.70 0.05  Passage Rate--Species 1
1   Stochastic  ( Passage Rate )
0.73 0.05  Passage Rate--Species 2
0  Harvesting
0 -1 -1    Minimum fish
0  Beginning Node
Gold Ray Dam         Node 2
1  Order
1  Number of Branches
3  is the node will be going to
1     Stochastic  ( Passage Rate )
```

```
0.95 0.005  Passage Rate--Species 1
1  Stochastic  ( Passage Rate )
0.95 0.005  Passage Rate--Species 2
0  Harvesting
0 -1 -1    Minimum fish
2  Between Node
Savage Rapids Dam        Node 3
2  Order
1  Number of Branches
4  is the node will be going to
1     Stochastic  ( Passage Rate )
0.95 0.005  Passage Rate--Species 1
1  Stochastic  ( Passage Rate )
0.95 0.005  Passage Rate--Species 2
0  Harvesting
0 -1 -1    Minimum fish
2  Between Node
Confluence Rogue-Applegate       Node 4
3  Order
1  Number of Branches
5  is the node will be going to
1     Stochastic  ( Passage Rate )
0.98 0.003  Passage Rate--Species 1
1  Stochastic  ( Passage Rate )
0.98 0.003  Passage Rate--Species 2
0  Harvesting
0 -1 -1    Minimum fish
2  Between Node
Canyon         Node 5
4  Order
1  Number of Branches
6  is the node will be going to
1     Stochastic  ( Passage Rate )
0.97 0.003  Passage Rate--Species 1
1  Stochactis  ( Passage Rate )
0.97 0.003  Passage Rate--Species 2
0  Harvesting
0 -1 -1    Minimum fish
2  Between Node
Estuary         Node 6
5  Order
1  Number of Branches
7  is the node will be going to
1     Stochastic  ( Passage Rate )
0.55 0.07  Passage Rate--Species 1
1  Stochastic  ( Passage Rate )
0.55 0.07  Passage Rate--Species 2
```

```
0  Harvesting
0 -1 -1    Minimum fish
2  Between Node
Ocean                   Node 7
6  Order
1  Number of Branches
8  is the node will be going to
1     Stochastic  ( Passage Rate )
0.117 0.010  Passage Rate--Species 1
1     Stochastic  ( Passage Rate )
0.117 0.010  Passage Rate--Species 2
0  Harvesting
0 -1 -1    Minimum fish
3  Between Node and it is the mouth of river ( fish out ).
Ocean                          Node 8
7  Order
1  Number of Branches
9  is the node will be going to
-1  No Stochactis  ( Passage Rate )
1.0  Passage Rate--Species 1
-1  Stochactis  ( Passage Rate )
1.0  Passage Rate--Species 2
1  Harvesting Party
1  Party number
0  No special harvest levels
1     Stochastic  ( Harvest Rate )   Party 2
0.33000 0.07  Harvest Rate--Species 1
1     Stochastic  ( Harvest Rate )
0.33000 0.07  Harvest Rate--Species 2
0 -1 -1    Minimum fish
5  Between Node and it is the mouth of river ( fish back ).
Estuary                        Node 9
8  Order
1  Number of Branches
10 is the node will be going to
1     Stochastic  ( Passage Rate )
0.76 0.04  Passage Rate--Species 1
1  Stochastic  ( Passage Rate )
0.76 0.045  Passage Rate--Species 2
1  Harvesting Party
2  Party number
0  No special harvest levels
1     Stochastic  ( Harvest Rate )   Party 2
0.075377 0.0030  Harvest Rate--Species 1
1  Stochastic  ( Harvest Rate )
0.073456 0.0030  Harvest Rate--Species 2
0 -1 -1    Minimum fish
```

```
5  Between Node and it is the mouth of river ( fish back ).
Canyon                Node 10
9  Order
1  Number of Branches
11  is the node will be going to
1     Stochastic  ( Passage Rate )
0.94 0.006  Passage Rate--Species 1
1  Stochastic  ( Passage Rate )
0.95 0.005  Passage Rate--Species 2
0  Harvesting Party
0 -1 -1    Minimum fish
2  Between Node
Confluence                 Node 11
10 Order
1  Number of Branches
12 is the node will be going to
1     Stochastic  ( Passage Rate )
0.96 0.005  Passage Rate--Species 1
1     Stochastic  ( Passage Rate )
0.97 0.004  Passage Rate--Species 2
1  Harvesting Party
2  Party Number
0  No special harvest levels
1     Stochastic  ( Harvest Rate )   Party 2
0.027064 0.0025  Harvest Rate--Species 1
1  Stochastic  ( Harvest Rate )
0.030895 0.0028  Harvest Rate--Species 2
0 -1 -1    Minimum fish
2  Between Node
Savage Rapids Dam               Node 12
11  Order
1  Number of Branches
13  is the node will be going to
1     Stochastic  ( Passage Rate )
0.82 0.04  Passage Rate--Species 1
1     Stochastic  ( Passage Rate )
0.85 0.035  Passage Rate--Species 2
0  Harvesting Party
0 -1 -1    Minimum fish
2  Between Node
Gold Ray Dam               Node 13
12  Order
1  Number of Branches
14  is the node will be going to
1     Stochastic  ( Passage Rate )
0.73 0.060  Passage Rate--Species 1
1     Stochastic  ( Passage Rate )
```

```
0.78 0.055  Passage Rate--Species 2
1  Harvesting Party
3  Party Number
0  no special harvest levels
1      Stochastic   ( Harvest Rate )   Party 3
0.221017 0.0180  Harvest Rate--Species 1
1      Stochastic   ( Harvest Rate )
0.213901 0.0190  Harvest Rate--Species 2
0 -1 -1    Minimum fish
2  Between Node
Hatchery/Spawning      Node 14
13  Order
0  Number of Branches
1      Stochastic   ( Passage Rate )
0.79 0.05  Passage Rate--Species 1
1      Stochastic   ( Passage Rate )
0.88 0.03  Passage Rate--Species 2
0  Harvesting
0 -1 -1        Minimum fish
1  Ending Node
1  Number of Beginning Nodes
1  Location of Beginning Node
0  SmoltsF     of species 1
0      "       of species 2
5923245  Minimum Spawning Capacity of species 1
0        Minimum Spawning Capacity of species 2
5923245  Minimum Spawning Capacity of species 1
29000000  Minimum Spawning Capacity of species 2
1  Number of Ending Nodes
14  Location of Ending Node
1  Location of Beginning Node
0.0 0.0 1836.0 2691.0  % FEMALE * FECUNDITY of species 1
0.0 0.0 1836.0 2691.0  % FEMALE * FECUNDITY of species 2
0.5 0.25    MEAN AND STANDARD ERROR FOR RIVER_LEVEL
10     River Level Distribution for species 1   Down
0.94 0.96 0.97 0.98 1.00 1.00 1.02 1.03 1.03 1.04
10     River Level Distribution for species 2   Down
0.95 0.97 0.97 0.98 1.0 1.01 1.02 1.03 1.03 1.05
0.5 0.25    MEAN AND STANDARD ERROR FOR RIVER_LEVEL
10      River Level Distribution for species 1   Up
0.94 0.95 0.96 0.96 0.97 1.0 1.01 1.02 1.03 1.04
10      River Level Distribution for species 2   Up
0.94 0.96 0.96 0.97 0.97 1.01 1.02 1.02 1.03 1.05
Y          The Upwelling Tables are being used
0.5 0.25   Mean and Standard Error for use in UPWFAC_GEN
10       UPWELLING TABLE SPECIES 1
0.77 0.87 0.89 0.93 0.94 1.04 1.09 1.11 1.13 1.20
```

```
10      UPWELLING TABLE SPECIES 2
0.77 0.87 0.89 0.93 0.94 1.04 1.09 1.11 1.13 1.20
5923245  21498889   [3.128528] Initial Eggs Species 1,2-Lag = 1
5923245  21498889   [3.128528] Initial Eggs Species 1,2-Lag = 2
3.128528 0.671 1.0      Egg-to-fry parameters Species 1
3.128528 0.671 1.0      Egg-to-fry parameters Species 2
  6815  17966   3717  Lag 0  Species 1
     0  17966   3717      1
     0      0   3717      2
     0      0      0
 16185  36783  13987  Lag 0  Species 2
     0  36783  13987      1
     0      0  13987      2
     0      0      0
```

APPENDIX C

Format for the Computer Model Input File

The following is the input format for the fish simulation program. The input is in free form, i.e. a value or a character string is separated by a comma or by one or more spaces.

Notation used throughout this format file is:

```
Y = Yes,
N = No,
NAME(#) represents a character string, with a maximum
    length of '#' characters,
I represents an integer value,
R represents a real value (must have decimal point),
I1,...,Ir  is a series of 'r' integers in row form, i.e.
    all numbers are entered on the same line,
I1,...,Ic  is a series of 'c' integers in column form, i.e.
    only one number is entered per line,

These last two forms are also used for types of input other
    than integer.
```

BEGINNING INFORMATION

```
A1: I       / Number of model runs.
A2: I       / Random seed.
A3: I       / Number of years for each simulation.
A4: I1, I2  / I1 = # of lag years, I2 = # of delay
                   periods.
A5: I       / Number of species.
A6: I       / Number of harvest parties.
```

SPECIES INFORMATION

```
Repeat B1.B4 for each of the species declared in [A5:I]
B1: NAME(20)  / Species name.
B2: I          / I = 0 if using ocean-environment factors,
                 I = 1 if not.
B3: R1,...,Rr / Proportion of fish directed straight through the
                  model [I1] and to each delay period--r =
                  [A4:I2] + 1.

Repeat B4 [A4:I2] + 1 times, i.e. for each age class
B4: R1,...,Rr / Age-class weight for each harvest party,
                r = [A6:I].
```

HARVEST INFORMATION

```
C1: NAME(30)1,...,NAME(30)c / Harvest party names, c = [A6:I].

Repeat C2 for each of the species declared in [A5:I]

Repeat C2 for each of the harvest parties declared in [A6:I]
C2: R1,...,Rr / Age-class price per pound, r = [A4:I2] + 1.
```

NODE INFORMATION

```
D1: I1, I2    / I1 = # of nodes, I2 = # of the node where
                 delayed fish re-enter the model.

Repeat D2.D5 [D1:I1] times (for each node)
D2: NAME(20)  / Name of the node.
D3: I         / Hierarchical order of node, I = 0 for
                 beginning nodes.
D4: I         / Number of branches for fish leaving node, I = 0
                 for ending nodes.
D5: I1,...Ir  / Node numbers for each branch, r = [D4:I],
                 skipped if [D4:I] = 0.

Repeat D6.D7 for [A5.I] times ( for each species)
D6: I         / I = -1 for non-stochastic passage rate,
                I = 0 for uniformly-distributed PR,
                I = 1 for normally-distributed PR.
D7: R1, R2    / if [D6:I] = 0, R1, R2 = Upper, Lower
                 distribution limits,
                if [D6:I] = 1, R1, R2 = Mean, S.E.,
                skipped if [D6:I] = -1.

D8: I         / Number of harvest parties allocated catch
                 at the node.
D9: I1,...,Ic / Harvest party's number--from order
                 entered at C1--c = [D8:I],
                skipped if [D8:I] = 0.

Repeat D10.D12 for each active harvest party
D10: I, R1,...,Rr / I = Number of years for special
                     start-of-run harvest rate,
                    R1.Rr are the special rates for each
                     species, skipped if [D6:I] = 0--
                     r = [A5:I].

Repeat D11.D12 for [A5:I] times
D11: I         / I = -1 for non-stochastic harvest rate,
```

```
                  I = 0 for uniformly-distributed HR,
                  I = 1 for normally-distributed HR.
D12: R1, R2     / if [D6:I] = 0, R1, R2 = Upper, Lower
                   distribution limits,
                  if [D6:I] = 1, R1, R2 = Mean, S.E.,
                   skipped if [D6:I] = -1.

D13: R1,...,Rr  / R1 = Number of years start-of-run for minimum
                    passage for fish leaving the node.
                  R2.Rr are the minimum numbers for each species
                    --r = [A5:I] + 1,
                  If no minimum passage set R2.Rr = -1.

D14: I          / Node indicator
                    I = 0 for initial node,
                    I = 1 for terminal node,
                    I = 2 for river node,
                    I = 3 for ocean node with delay assignments,
                    I = 5 for ocean node where fish return from
                      delay modules,
                    I = 4 for other ocean nodes.

If the node is a terminal node, then include D15
D15: I          / I = node number of the corresponding initial
                    node.

If D4:I > 1 then include D16
D16: R1,...,Rc  / R1.Rc = proportion of fish continuing to each
                    node immediately following the current node-
                    -c = [D4:I].
```

BEGINNING AND ENDING NODE INFORMATION

```
E1: I           / I = The total number of beginning nodes.

Repeat E2.E5 for [E1:I] times
E2: I           / I = The node number of a beginning node.

Repeat E3 for [A5:I] times
E3: I1,...,Ic   / Number of years that eggs are restricted to
                    initial year levels--c = [A5:I].

Repeat E4 for [A5:I] times
E4: R1,...,Rc   / Minimum spawning capacity for each species--
                    c = [A5:I].
```

Repeat E4 for [A5:I] times
E5: Rl,...,Rc / Maximum spawning capacity for each species--c = [A5:I].

E6: I / Number of ending nodes.

Repeat E7.E8 for [E6:I] times
E7: I / I is the node number of an ending node.

E8: I / I is the node number of the beginning node corresponding to [E7:I].

Repeat E9 for [A5:I] times
E9: Rl,...,Rr / (% of females x eggs per female) for each age group--r = [A4:I2] + 1.

PASSAGE RATE MODIFICATION FACTORS

Fl: Rl,R2 / Rl is the mean, R2 is the standard error for the truncated normal distribution used for selecting downstream passage rate modifiers.

Repeat F2.F3 for [A5:I] times
F2: I / Number of elements in the distribution (10).

F3: Rl,...,R10 / Proportional modifiers for downstream passage.

F4: Rl,R2 / Rl is the mean, R2 is the standard error for the truncated normal distribution used for selecting upstream passage rate modifiers.

Repeat F5.F6 for [A5:I] times
F5: I / Number of elements in the distribution (10).

F6: Rl,...,R10 / Proportional modifiers for upstream passage.

F7: Y,N / Y if ocean environmental modifier is used.

F8: Rl,R2 / Rl is the mean, R2 is the standard error for the truncated normal distribution used for selecting ocean environmental modifiers.

Repeat F2.F3 for [A5:I] times
F2: I / Number of elements in the distribution (10).

```
F3: R1,...,R10   / Proportional modifiers for ocean survival.
```

STOCK INFORMATION

```
Repeat G1 for [A4:I1] times
G1: R1,...,Rr    / Initial eggs for each species--r = [A5:I].

Repeat G2 for [A5:I] times
G2: R1,R2,R3     / Parameters for the egg-to-fry conversion.

Repeat G3.G4 for [A5:I] times
Repeat G3.G4 for [A4:I1] + 1 times
G3: R1,...,Rr    / Number of fish existing in ocean delay
                   modules at the start of the run--
                   r = [A4:I2]--beginning with module
                   re-entering model first.
```