THE SALMON CASE STUDY: AN OVERVIEW

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This paper is intended as a general perspective on the Salmon Case Study for 1974-75. We review the reasons for choosing the case, indicate how salmon management policy has evolved to the present day, and describe the several research strategies that we are following in attempting to generate alternative policies for the future. We hope that the framework outlined here will prove more generally applicable to problems of renewable resource management.

Rationale

The case study is centered on a single river basin, the Skeena System in Central British Columbia. This system is one of about a dozen major salmon producing rivers around the rim of the Pacific Ocean from Japan to California. Salmon are born in the river, then go to sea for one to three years. At sea they may be exploited by an international mix of fishing fleets, but most of the harvest occurs near the river mouth when the adult fish return to spawn and die. Because they have an orderly life cycle, a concentrated period of harvest, and because population size can be easily determined, salmon are considered the most manageable of the large world fisheries. Many fundamental concepts of fishery management (stock-recruitment relationships, economics of exploitation, etc.) have stemmed largely from studies on salmon.

We had five basic reasons for choosing the Skeena River as a case study:

1) Our results should be generalizable to other fisheries around the world, and perhaps to other renewable resources.
2) Our results might have real benefits to people; the Skeena Fishery employs over 1000 men, representing a gross income of several million dollars per year.
3) There is an extraordinary history of data on the ecological dynamics of the system.
4) There is a solid history of data on actual management performance in the absence of systems analysis.
5) Perhaps most important, there is a clearly defined client for our results; we have a good working relationship with Environment Canada , the primary agency responsible for salmon management in British Columbia.

Historical Background

Figure 1 shows historical changes in the two major salmon populations of the Skeena River. Prior to 1950 there was essentially no management, and the system was evolving toward a predator-prey equilibrium between the fishing fleets and the salmon stocks. Fearing that the stocks might be driven to extinction, the Canadian government began instituting catch regulations in the early 1950s. Other nations (particularly Japan) were excluded from the fishery by international agreement (the so called abstention arrangements) during this period.

Stock sizes began to recover after the mid 1950s, but a disastrous economic situation had arisen by 1970: investment in the fishery was not controlled, so a larger and larger fleet was forced to share the same catch. Beginning in 1970 a program of license limitation was initated to dramatically reduce the fleet size and presumably make the industry more economically efficient.

Around 1970 it was realized that maximum average catches were likely to result from a "fixed escapement" policy, in which the same number of fish are allowed to spawn each year. This policy was adopted and forms the basis for present management.

British Columbia is in a period of rapid economic growth, so recent years have seen considerable pressure for development of the Skeena Watershed. Several hydroelectric dams have been proposed, and it is likely that there will be urban and industrial development near the river mouth. Thus Environment Canada is having to face a much broader set of issues and institutions (Table 1). So far, the policy has been to completely oppose any watershed development that might influence salmon populations; this unyielding attitude will almost certainly have to change in the next few decades, especially in relation to urban and industrial development.

Framework for Analysis

There is no single problem about salmon to which we can direct appropriate systems techniques. Our case study instead deals with a hierarchic set of decision problems, as shown in Figure 2. We assume that broad decisions about regional resource allocation will establish a (time varying) potential for salmon production. Within this potential, there are some basic strategy options for dealing with the enormous stochastic variation in production from year to year (figure 1). Given a production strategy, there are several options for distribution (utilization) of the catch, ranging from no control (open entry "commons" fishery) to a complete government monopoly where the entire catch is taken by a single large trap. The production and utilization strategies that we may suggest are of no value unless we can show that these strategies can actually be implemented; thus we are examining several possible implementation tactics. Finally, we are concerned with mechanisms to translate the variable catch stream produced by management actions into a more stable and predictable income stream for the fishermen.

We are attempting to analyze the decision system of figure 2 in two steps. First, we are doing a series of simple optimizations across options at each decision level, assuming an optimal input pattern from the higher levels and perfect control at the lower levels. This first step should allow us to discard some options that are clearly inferior under most objective functions. Second, we are trying to evaluate a sample of the more promising overall options (combinations of options from all five levels) for changes in optima that might result from policy failure, imperfect control at the various levels, or changes in objective functions. This second step is essentially a simulation exercise.

Analytical Procedures

This section gives an overview of the decision options and analytical procedures we are using for each decision level in figure 2. Each analysis described here is intended to provide a different perspective for decision makers; we feel that a variety of perspectives should be useful even if no single coherent decision framework can be developed.

Level I: Regional Resource Decisions

In cooperation with Environment Canada, the British Columbia Resources Secretariat (forestry, recreational fisheries and wildlife), and B.C. Hydro (energy), we have developed a large scale simulation model for the Skeena System. This model is designed to examine long range (30-50 year) patterns of watershed development, and it consists of five basic components:

1. A synthetic hydrology submodel to generate runoff patterns (monthly) across the watershed.
2. A hydroelectric dam submodel that can accept alternative siting, construction timing, and operating decisions, and can produce regulated storage and water flow patterns for any runoff input sequence.
3. A water quality submodel to simulate transport and degradation of pollutants, particularly silt (associated with hydro dam construction and forestry).
4. A population dynamics submodel for the major salmon and steelhead subpopulations (there are nineteen of these) that use various parts of the watershed; population changes and yields are represented as a function of harvesting policy, water flow, water quality, access to spawning areas (as affected by dams and forestry operations), and enhancement policy (hatcheries, spawning channels, etc.)
5. A recreational fishing submodel to predict recreational demand and catches in relation to

fishing quality and to alternative regional population growth patterns (as might arise from different economic development policies).

This model can accept a bewildering variety of development policies and tactical options (e.g. fishways to allow salmon passage around dams); so far we have used it only in a gaming format with the cooperating agencies to get a broad picture of potential development impacts on salmon. Our results suggest that there are only a few hydroelectric development options which would seriously affect the salmon, and these options have low priority with B.C. Hydro. Clearly we need a more systematic procedure for identifying, testing, and evaluating the various broad options.

Level II: Production Strategy Decisions

The regional resource modelling should provide alternative operating contexts for salmon production, expressed in terms of potential stock productivities and equilibrium stock sizes (carrying capacities) over time. For any context, we can use stochastic dynamic programming to derive optimal control laws for salmon harvesting. These control laws should specify optimal harvest rate (proportion of fish caught each year) as a function of stock size, for a variety of possible objective functions.

We have developed such optimal control solutions under the assumption that watershed conditions will not change, for objective functions emphasizing tradeoffs between mean and variability of catches, and for different enhancement options.[1] These solutions take account of the enormous stochastic variation that has been observed in salmon production; they should also be close to optimal for management response to occasional human disturbances (like dam construction, pulses of toxic mine waste, etc.) which do not have a persistent effect on watershed condition but may cause dramatic stock collapse for a few years.

Level III: Utilization Strategy Decisions

Table 2 shows a spectrum of options for organization of the fishing industry, and a qualitative rating of these options for several benefit indicators. Our plan is to develop this options-indicators table much more fully, substituting a more comprehensive and qualitative set of indicators. Some of these indicators can be readily computed from historical data; others can be developed by making very long stochastic simulations using catch distributions generated in the level II analysis.

We expect that a small set of dominant options will emerge from the spectrum in table 2. This smaller set can be examined in relation to a restricted set of indicators, using multi-attribute utility theory. Rather than specify a single best option, we would prefer to

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[1]Walters, C.J. 1975 IIASA Working Paper #
Hilborn, R. 1975 IIASA Working Paper #

identify ranges of indicator weightings for which each option would be optimal (inverse objective function analysis). From preliminary analyses, the most promising options appear to be:

1. Open entry with taxation to limit investment and provide insurance against disasters.
2. Restricted entry with licenses valid only in specified fishing territories.
3. Monopoly trap system, doing away entirely with the fishing fleet.

Present management is close to option 2; evaluation of option 1 will require us to develop a good dynamic model for investment and disinvestment in the fishing fleet ("population dynamics" of the fishermen).

Level IV: Implementation Tactics

The analyses at levels II and III can provide idealized targets for management, but they will remain academic exercises unless we can demonstrate practical ways to implement them. The biggest practical difficulties occur within each fishing season, when regulations are modified from week to week as catches accumulate and stock size forecasts are revised. At present the key control variable is the number of days open for fishing each week, though there is some regulation of the type of fishing gear (size and type of nets). Though there is license limitation, fishing effort can change dramatically from week to week; fishermen are free to decide when to go out, and whole fleets can move from one river system to another.

A few of the strategies at level III call for the elimination of within-season regulation of total catch, but in all cases it will be necessary to have mechanisms for distributing the catch across the fishing season; processing (packing and cannery) facilities are limited, and there is risk of genetic damage to the stocks if the fish running at any time receive much heavier exploitation than the fish running at other times.

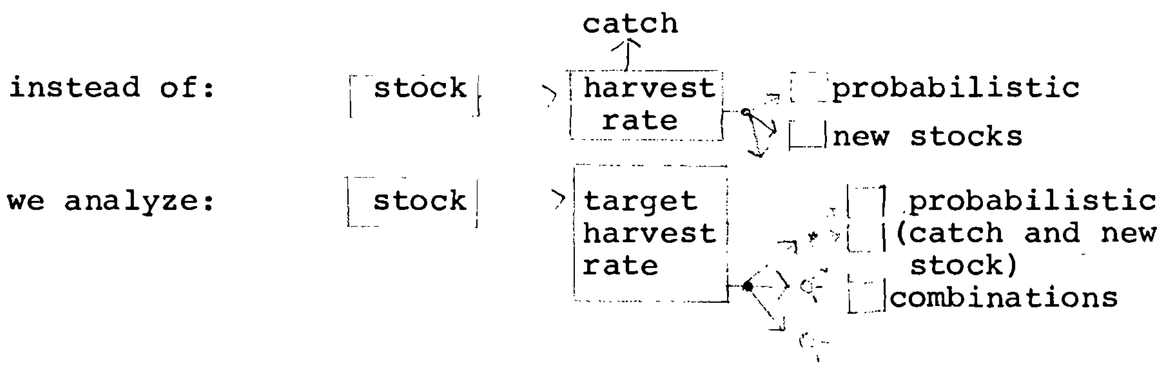
There are two extreme options:

1) An elaborate adaptive control system involving statistical run and effort forecasts, close monitoring of catches and escapements, and weekly modification of regulations.

2) A simpler and less costly fixed regulation system in which preseason stock forecasts are used to set a schedule of weekly regulations that is not modified during the fishing season.

Figure 3 shows one possible structure for an adaptive control system; we have completed most of the data analysis necessary to fill in the functional components of this system. Using the data and relationships developed for adaptive control, it is a simple matter to design reasonable rules for establishing fixed regulations.

We can test alternative regulatory options by stochastic simulation. Adequate data are available to establish bounds and probabilities for the variety of input situations (forecast errors, changes in timing of fish movements, changes in fishing power per unit of effort) which any control system is likely to face in practice. By computerizing the control system and feeding it a stochastic stream of input situations, we should be able to establish probability distributions for deviations from target catches. These probability distributions can then be used as input for simulation and optimization modelling at decision levels II and III. For example, we can do the stochastic dynamic programming for optimum harvest rates (level II) with an extra set of stochastic possibilities:



Level V: Lest We Forget People

Some management choices at decision levels II, III, and IV might produce good overall biological or economic returns yet be unacceptable or extremely harsh for the individual fisherman. Certainly the maximum yield, fixed escapement production policies are of this type: they result in the highest average catches, but also the greatest year-to-year variation in catches. Under current policy, fishermen will be forced to use existing federal and provincial unemployment insurance programs when no catches are allowed.

An alternative to current policy would be to internalize the unemployment insurance system, by taxing catches in the good years and feeding this money back to the fishermen in the bad years. The simplest system would be to allow each fishing boat to choose a minimum guaranteed income level, then impose a proportional tax on income above this level. Simulation and dynamic programming can be used to estimate the necessary tax rate for any desired minimum income level in conjunction with each possible management strategy from levels II and III.

An added benefit from some sort of tax-insurance system would be to give Environment Canada more flexibility in choosing basic harvest strategies. Under existing policy, it would probably be politically disastrous to shut down the Skeena fishery for even one year; any proposal of that sort would almost certainly be turned down by the Environment minister.

Coping With The Unexpected: Policy Resilience Analysis

For each of the five decision levels in figure 2, our analyses are explicitly directed at stochastic variability. However, it would be foolish to assume that we have thought of every possible source of variability and uncertainty, or that there will never be even more extreme conditions than we have detected and represented from historical data. It is easy to list a few of the possibilities:

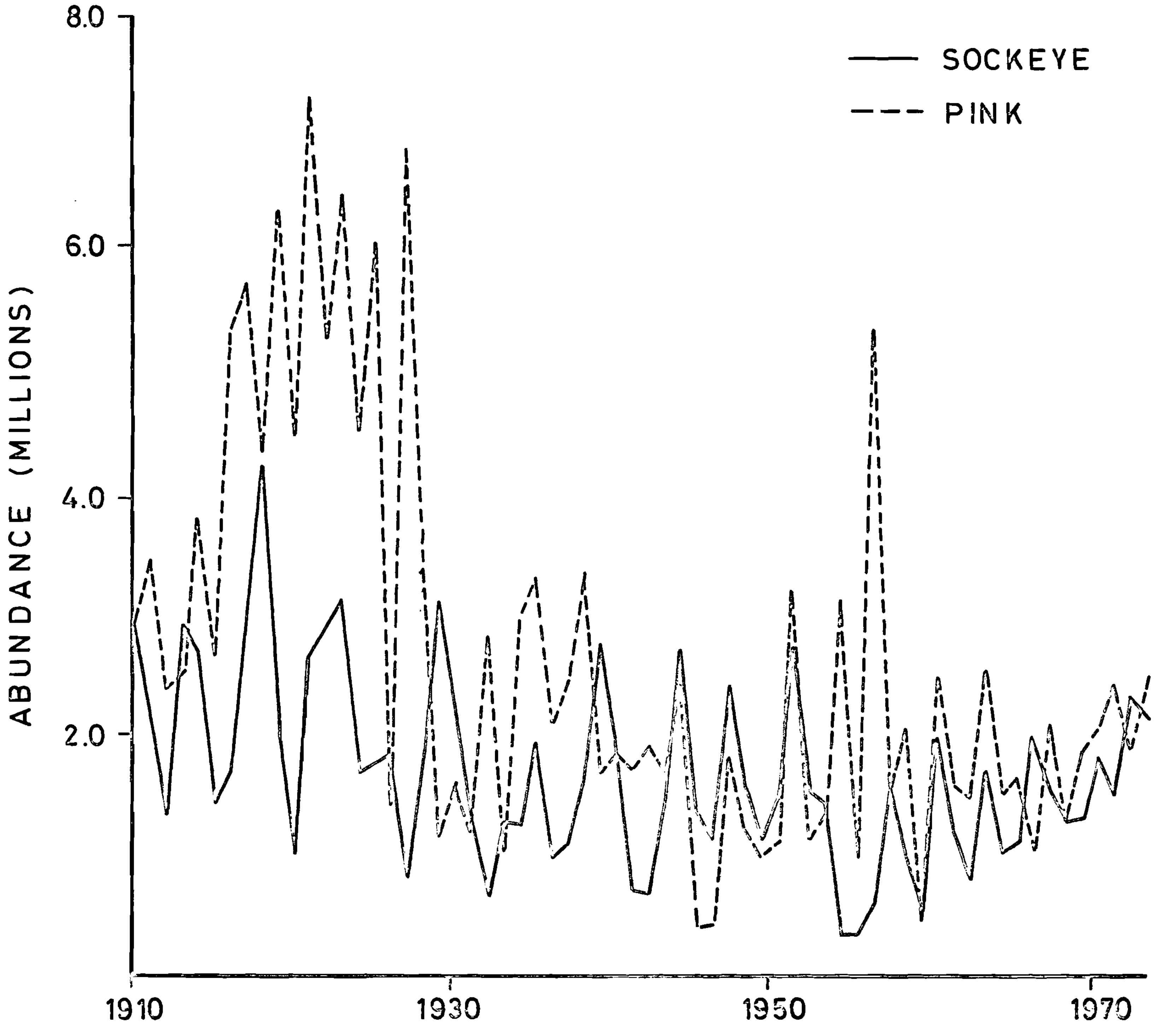
1) A new source of pollution in the watershed could decimate stocks before it could be detected and controlled.
2) The international treaty system could fail, resulting in overexploitation by high seas fishing.
3) Disease organisms, algae blooms, or some other agent could wipe out enhancement production (at least for a few years).
4) Several drought or flood years could occur in sequence, with especially disastrous effects on pink salmon.
5) An economic depression could drastically lower the value of catches, and stimulate the government to invest in other resource developments (e.g. hydroelectric dams).

The possibilities are almost endless, but the key point is that something bad is bound to happen, and policy combinations with poor performance in the face of the unexpected should be identified and avoided. For example it would be foolish to allow the development of a very large fishing fleet completely dependent on enhancement (hatchery) production; should any production failure occur, this fleet would become a serious economic burden (witness the Peruvian anchovetta fishery).

A new technique developed by Holling and Hilborn may help us to identify such dangerous policies. The technique involves computation of a "resilience number" or indicator for each policy. This number is a measure of the persistence and seriousness of undesirable states that may arise if the policy fails. That is, it is a measure of the resilience of the managed system to bounce back (recover) after a policy failure.

The hope is that we will be able to identify resilient policy combinations that are nearly as productive as the best of the unsafe options. This is not likely; usually the most productive or profitable policies are also the most risky. We are not in a position to judge and weigh the risk aversions of the various interest groups involved in salmon management; these are political problems. Our task then will be to present the production-risk trade-off so that it can be clearly understood by decision makers.

FIGURE 1. Historical changes in Skeena River salmon populations.



8.0
6.0
4.0
2.0
ABUNDANCE (MILLIONS)
1910
1930
1950
1970
SOCKEYE
PINK

ELEMENTS OF THE SALMON STUDY

CONFLICTING OBJECTIVES

KEY INSTITUTIONS	PROBLEM LEVELS I SALMON INTRASEASON TACTICS	II SALMON LONG RANGE STRATEGIES	III RIVER BASIN AND REGIONAL MANAGEMENT
INTERNATIONAL: SALMON COMMISSION	Equity in distribution of catches among national fleets	Sustained yields	Maintenance of salmon habitats
FEDERAL: ENVIRONMENT CANADA	Meeting long range targets, equity among users, economic efficiency	Sustained yields, mix of species stocks, enhancement systems	Maintenance of salmon habitats
PROVINCIAL: RESOURCE SECRETARIAT	Opportunities for recreational users	Equity for recreational users	Recreational fisheries and wildlife, forestry
PROVINCIAL: B.C. HYDRO	Short term profits and employment	Stable economic returns and employment	Regional mix of resourc industries, induced economic development
INDUSTRY AND ECONOMIC DEVELOPMENT AGENCIES	Short term profits and employment	Stable ecomomic returns and employment	Regional mix of resourc industries, induced economic development

TABLE 1. Institutions and issues in salmon management.

DECISION FRAMEWORK FOR THE SALMON CASE STUDY

LEVEL

I REGIONAL RESOURCE DECISIONS:

II PRODUCTION STRATEGY DECISIONS:

III UTILIZATION STRATEGY DECISIONS:

IV IMPLEMENTATION TACTICS:

V LEST WE FORGET PEOPLE:

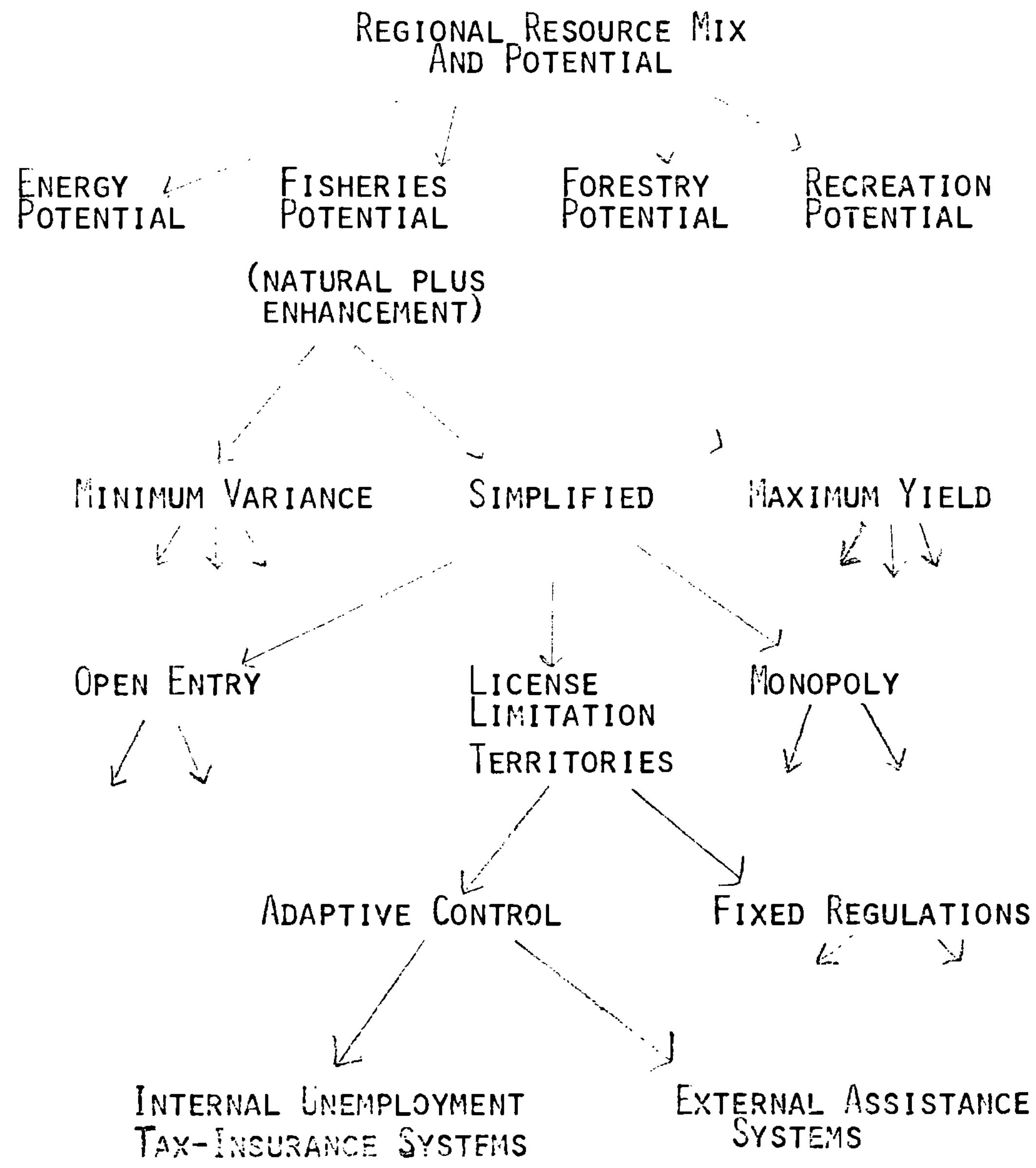


FIGURE 2. Salmon management seen as hierarchy of decision problems.

TABLE 2. Strategic and tactical options for organization of the salmon fishery.

STRATEGIES	TACTICAL OPTIONS	Annual Management Effort	Employment	Profits	Catch	Probability of Policy Failure	Immediate Social Change
OPEN ENTRY	*No catch control	none	high	O-very low	low	highest	+
	*Fixed season catch control	low	high	O-very low	medium	high	+
	*Adaptive catch control	medium-high	high	O-very low	high	low-medium	+
	*tax-insurance control	low	high	O-very low	medium	high	+
RESTRICTED ENTRY	*No catch control	very low	medium-high	high	high	high	+
	*Fixed season catch control	low	medium	high	high	medium	O
	*Adaptive catch control	medium-high	medium	high	very high	low	O
	*Fishing territories	low	medium-low	high	high	low	-
MONOPOLY TRAP SYSTEM	*Fixed season	high	low	very high	very high	low	-
	*Adaptive catch control	very high	low	very high	very high	none	-

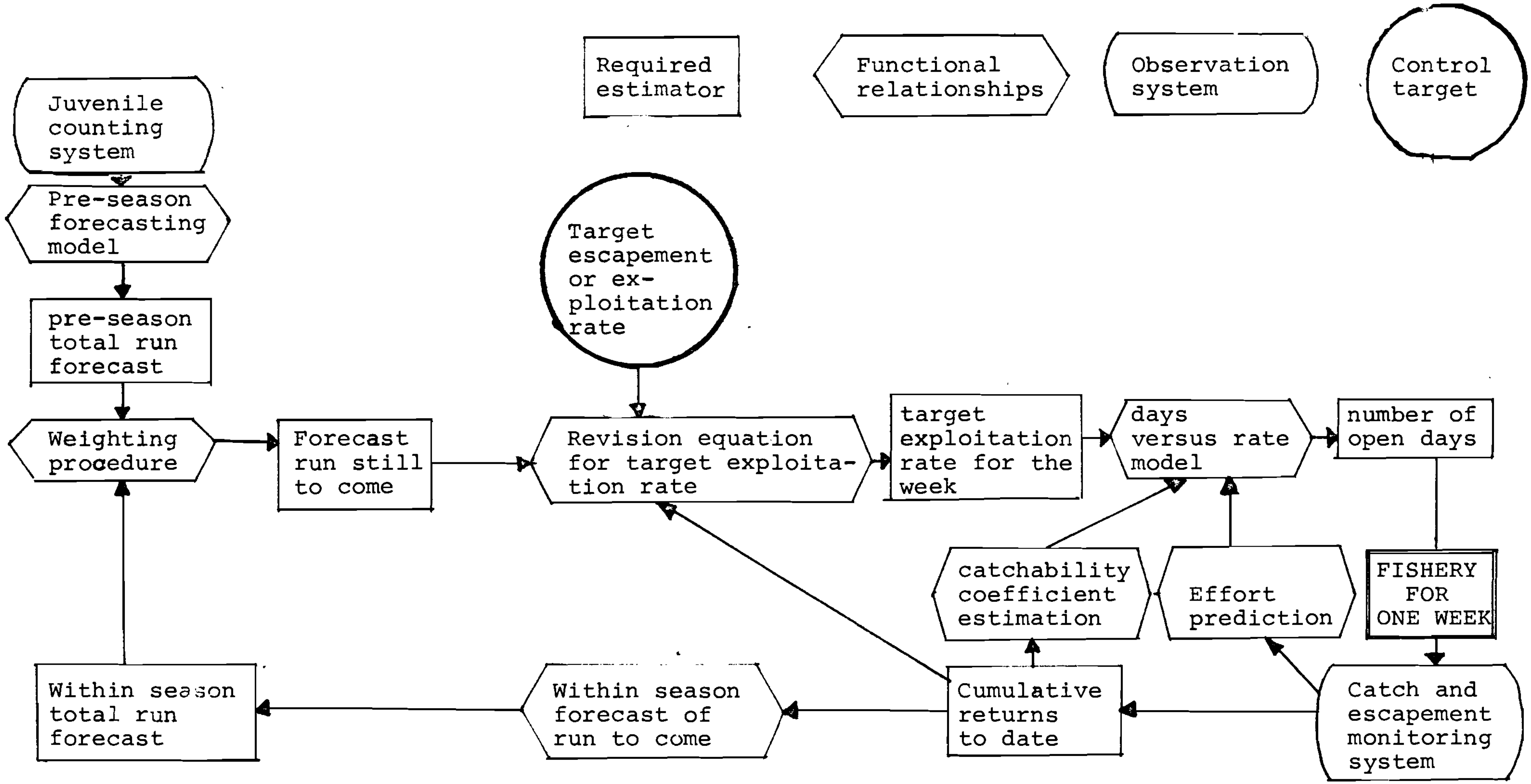


FIGURE 3. A control system structure for within-season salmon management.