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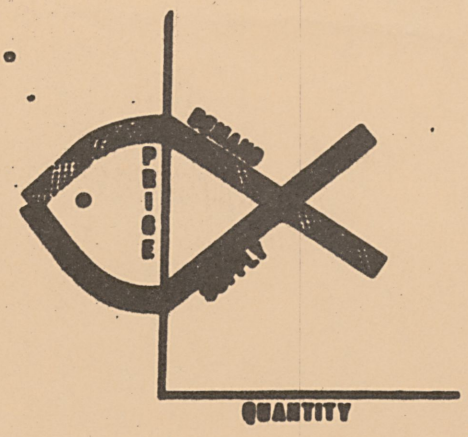

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A Detailed Pacific Coast Salmon Model for
Studies of Gear Limitation and Stock Allocation
in the Washington Fisheries

by

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April 1973

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ABSTRACT

A large scale, comprehensive computer simulation model of the Pacific coast salmon fisheries was constructed. The model is most detailed for the Washington fisheries. The computer base is an altered version of the program GAMES. Thirty-five major salmon stocks are modelled spawning in areas from the Columbia River to the Fraser River. Gill net, purse seine, sport and troll gears are represented in ten fishing locations from Oregon to southeastern Alaska. Population estimates are derived using virtual population techniques. Stocks are subject to natural, fishing and catch-release mortality. Migration to spawning grounds is modelled. Spawner-recruit relationships are specified by Beverton and Holt-type equations. Harvester activities modelled are number of units of gear operating, time spent fishing and relative fishing power. Harvester economics considered are fixed and operating costs and net profit from catch. Harvesters are regulated by a general regulator varying season length and minimum size limit.

A DETAILED PACIFIC COAST SALMON MODEL FOR STUDIES OF GEAR LIMITATION AND STOCK ALLOCATION IN THE WASHINGTON FISHERIES

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INTRODUCTION

The purpose of this research is to construct a mathematical model of the Washington State salmon fisheries. This study is a continuation of that done by James Newton under the West Coast Fishing Industry contract (Newton, 1972). This research extends the Newton study by the use of a more detailed and realistic definition of exploited salmon stocks than was available before for this study. The computer program base used by Newton has been expanded for the stock and harvester sectors. Economic considerations above landed value, the emphasis of Newton, are not included.

The ultimate goal of this research is to provide a more detailed, comprehensive management tool than is currently available for use by salmon regulatory agencies. The model hopefully will give insight to the implications of proposed management decisions on stocks and harvesters.

The model presented in this paper is a large scale, comprehensive system simulating salmon fisheries from Oregon to Southeastern Alaska, as they intercept stocks utilized by the Washington fisheries. Stocks spawning in streams from the Columbia River to British Columbia are included as far as they are important to the Washington fisheries.

In the hierarchy of models, the model presented here is generalized as opposed to specific. In this light, the intended use of the model is as an aid to the study of the general effects of various management strategies on future production and value. It is not intended to be a predictor of absolute detail. It is not intended that this model be able to give detailed predictions on the level of, say, the implications to the escapement of Spring Creek Hatchery fall chinook of a change in hook size in the Greys Harbor troll fleet. What the model will do is indicate the general responses of stocks and harvesters to pertubations such as a decrease in effort in the troll fishery off the west coast of Vancouver Island. While being essentially generalized with respect to the Pacific coast, the model is most detailed for the Washington fisheries. The most important salmon stocks and fisheries of Washington in terms of catch and value have been included.

RELATED RESEARCH

This research is an extension of James Newton's Washington salmon fisheries study. Dr. Newton's approach was to represent the stock sector in a highly aggregated form and to concentrate on a detailed description of the economic and marketing aspects of the system. For purposes of his model, Dr. Newton restricted membership in a stock to fish caught in the Washington fisheries, ignoring out-of-state populations. Dr. Newton assumed a constant escapement of .2 of the population. He made no attempt to describe spawner-recruit relations.

In his thesis, Dr. Newton investigated the economic results of eliminating certain existing troll fisheries under assumptions allowing the excess fish to be taken by all other harvesters, by sportsmen and other trollers and by sportsmen alone. Probably the most obvious flaw in the Newton model was the inclusion of troll fisheries in Puget Sound and the Columbia River competing with other fisheries in these areas. In fact, troll fisheries do not exist in these areas and their elimination is meaningless.

This research concentrates on stock and harvester definition and allows migrating stocks to be subject to fishing pressures throughout their range. Actual fishing areas are represented in the model. Estimates have been obtained for all population parameters using existing data.

Spawner-recruit relations have been constructed from available data. Finally, the model is constructed to be run as a continuous system over a period of years, which was not the case in the Newton study.

The existing SALMON GAMES program has been extensively modified by Larry Gales to emphasize stock, harvester and regulator sectors. Processor, product and market sectors have been eliminated to make room for the expanded stock sectors.

OBJECTIVES

The first objective of this project is to define the physical and biological sectors involved in the Washington salmon fishery. That is, what stocks contribute to the fishery, in what locations are these stocks fished, both inside and outside Washington waters and how much gear in each location is devoted to the stocks. The investigation of migration routes and timing for spawning runs dictate when the model stocks are in the model fishing locations.

The second objective is to obtain estimates of various population parameters for the stocks and fishing parameters for the fisheries.

The final objective of the project is to validate, then exercise the model under the assumption of altered gear type composition in the model fishery areas. To illustrate possible uses of the system, two gear regulation strategies are tested. First, the effects of eliminating the Washington troll fishery, Newton's question, are investigated. Secondly, the effects of reducing gear in the troll fishery off the west coast of Vancouver Island are investigated.

THE MODEL

PROGRAM BASE

The program base for the model is an altered and reduced version of the program SALMON GAMES (Gales, 1972). GAMES is a multi-purpose, interactive resource management program which allows simulation of the major participants involved in harvesting and marketing a renewable natural resource. Sectors simulated are: stocks, locations, harvesters, regulators, processors, products and markets.

For this model GAMES has been modified by its author, Larry Gales, to emphasize stock, location, harvester and regulator interactions. Processor, product and market sectors have been eliminated. This modification was indicated by a desire to make a biologically oriented simulator, accounting for as many stocks and harvesters as possible. The limiting factor is computer storage capacity, which is just reached with the current system. The addition of economic considerations to even the most minimal extent would necessitate a reduction by 1/2 in the physical sectors, an unacceptable reduction in view of the goals of the research. According to Dr. James Crutchfield of the University of Washington Economics Department, limiting model economics to landed value, as done here, is realistic and actually more meaningful, given the unavailability of processor economic data.[1]

[1] personal communication.

STOCKS

The Washington salmon fisheries operate on 5 species: chinook, chum, coho, pink and sockege. In the model these species are represented by 35 stocks, each representing 1 species spawning in a particular geographic area. Stocks are further separated by direction and path of spawning migration and, in the case of chinook, by fall and spring runs and sex. A model population is defined as a stock residing in an initial location. Table 1 lists the stocks considered in the model and their ranges. Migration direction refers to the spawning migration.

Stocks chosen are those contributing the most catch to the fisheries concerned. In some instances the fall run of chinook stock is chosen for inclusion, while the spring run is not. In these cases the spring runs were negligible when compared to runs of other stocks.

It is necessary to group stocks spawning in a particular geographical area in order to make the system fit into available storage. For example, chinook stocks from the 20 state hatcheries producing chinook runs on the Columbia River system are combined with the natural runs as 4 stocks encompassing males, females, falls and springs. If the same split were made for the 20 hatchery stocks, the result would be 80 stocks for this one stream alone. The model trades detail for generality and comprehensiveness.

TABLE 1. Stocks modeled, their geographic range and direction of spawning migration, Washington Salmon Fisheries Model.[a,b]

Species	Stock #	Stock Name	Type	Sex	Maximum Range	Direction of Migration
Chinook	1	Columbia R.	F	M	SE Alaska	S
	2			F		
	3		S	M		
	4			F		
	5		F	M	Oregon Coast	N
	6			F		
	7		S	M		
	8			F		
	9	Wash. Coast	F	M	SE Alaska	S
	10			F		
	11		F	M	Oregon Coast	N
	12			F		
	13	Puget Sound	F	M	North BC (E VI)	S
	14			F		
	15		F	M	North BC (W VI)	S
	16			F		
	17	Fraser R.	F	M	SE Alaska (E VI)	S
	18			F		
	19		S	M		
	20			F		
	21		F	M	SE Alaska (W VI)	S
	22			F		
	23		S	M		
	24			F		
Coho	25	Fraser R.			North BC (E VI)	S
	26				W. Vancouver I.	S
	27	S. Puget Sound			North BC (E VI)	S
	28				W. Vancouver I.	S
	29	Columbia R.			Wash. Coast	S
	30				Oregon Coast	N
Sockeye	31	Fraser R.			E. Vancouver I.	S
	32				W. Vancouver I.	S
(odd yr.) Pink	33	Fraser R.			W. Vancouver I.	S
Chum	34	Fraser R.			N. Puget Sound	N
	35	S. Puget Sound				S

[a]In some areas outside Washington there are local stocks of coho, chum and pink salmon which are not considered in this model, as they do not contribute to the Washington fishery.

[b]Chum and sockeye salmon are assumed to migrate as mature fish directly from ocean feeding areas where they are not subject to fishing. The presence of all stocks in only the listed fishing locations is for bookkeeping purposes and does not necessarily imply nonmigration to other locations.

Chinook are divided into fall and spring runs due to the program's requiring all fish of a particular stock to migrate at the same time, which for spring and fall chinook is an unacceptable generalization. Summer run chinook are combined with spring, an acceptable generalization given storage limitations. Chinook are further divided by sex. This is necessitated by the difference in maturity rates between males and females and by the concern expressed by management agencies for greater detail in this most important species.

LOCATIONS-HARVESTERS

Ten feeding-fishing locations are considered in the model. Various gears are associated with each location. Harvesters are modeled as 27 gear-location combinations. Gear-location relations are listed in table 2.

This version of the model considers 4 gear types: Gill net, purse seine, troll and sport. Reef net and native trap gears are not included. This omission of relatively incidental gear reflects the goal of the simulation, that is, to include the most important components of the system and, where size becomes a problem, to eliminate those of marginal importance to the big picture.

REGULATORS

The policies of regulators operating on harvesters in Alaska, British Columbia, Washington and Oregon are simulated in the model by one agency. The regulator controls harvesters by setting quotas and seasons and by limiting entry and gear efficiency.

TABLE 2. Modeled locations and gear, Washington Salmon Fisheries Model.[a,b,c]

location #	location	gear			
		gill net	purse seine	sport	troll
1	SE Alaska			X	X
2	North BC				X
3	West VI			X	X
4	East VI	X	X	X	X
5	North Puget Sound	2X	2X	X	X
6	Fraser River	X		X	
7	Southern Puget Sound	X	X	X	
8	Washington Coast			X	2X
9	Columbia River	X		X	
10	Oregon Coast			X	X

[a]Southern BC model fishing locations correspond to statistical areas as follows:

Model Location	Statistical Area
East VI	11-16
Northern PS	17-21
West VI	22-27
Fraser R	28,29

[b]Washington northern Puget Soung model fishing locations are those inside Cape Flattery and north of Admiralty Inlet.

[c]2X implies two fisheries of the same gear type operating in the area.

OPERATION OF THE MODEL

The model assumes a constant distribution of stocks over their ranges. Actual distribution of a stock can be pictured as a general milling between locations within that stock's range. This milling results in an essentially constant distribution over that range. This situation is modeled as fixed populations which are stock-area combinations.

As an illustration of the operation of the model, consider the movements of population 1 (SE Alaska) of stock 1 (male, north-migrating, fall run Columbia River chinook) through 1 year of model life.

1. At the beginning of model run, month 1 year 1, the STOCK sector divides the population into mature and immature fish. Assume for example, that (i) migration begins on May 1 (month 5) and that (ii) that the fishing season is from April 1 (month 4) to October 1 (month 10).
2. Immatures and matures are subject to natural mortality, M, during months 1 to 3. They are subject to monthly increments in growth.
3. In month 4 immatures and matures are subject to M. Matures and immatures are subject to area 1 specific fishing mortality F(1). If the length of individual fish exceeds the minimum size limit set by the regulator, that fish is kept. If its length is

less than the size limit, the fish is released and is subject to gear and age-specific gear damage mortality.

4. In month 5 immatures are further subject to M and F(1) as in month 4. Matures migrate from location 1 to location 2, northern British Columbia, and are there subject to M and F(2) for the amount of time they are resident in location 2.

5. For months 6 through 9 immatures remain in location 1 subject to M and F(1). Matures have migrated through fishing locations 3, 8 and 9 and have been subject to M and to fishing mortalities in those areas. On September 1 (month 9) the matures escape the terminal fisheries.

6. On October 1 (month 10) the fisheries on stock 1 population 1 end and for months 10 through 12 immatures are subject only to natural mortality, M.

While population 1 has been growing, migrating and suffering mortality, populations 2 through 5 of stock 1 have been acting similarly. On September 1 the matures of all populations of stock 1 escape and are combined as the escapement of stock 1, year 1. On January 1 of year 2, escapees are subjected to a species-specific spawner-recruit relation which yields age 1 recruits to the populations of

stock 1 according to the initial distribution. Recruitment takes place on January 1, year 3.

While stock 1 has been operating in the system, stocks 2 through 35 have been similarly active. Populations of stocks present in the same location have interacted and been subject to the same fishing mortality. Different gears operating in the location have competed among themselves and with natural mortality for the fish present.

During the year harvesters land their catches of stocks by month and receive revenue. They incur fixed and operation and harvest-related expenses and realize a net revenue.

The model runs for the number of years specified by the user. The user selects physical and economic statistics to be computed for the stocks and harvesters and for any combinations desired. Management schemes to be tested are stated in terms of stock, area and harvester specific size limits and season length and the numbers of units and efficiencies for harvesters. Management schemes can be altered by month or year and by separate run to simulate a continuing stock-harvester-regulator system.

PARAMETER ESTIMATION--STOCK SECTOR

There are 26 general types of parameters that affect the actions of the STOCK sector. These parameters are utilized by the program to simulate the population, growth, migration, mortality losses and spawner-recruit relationships of the model populations.

INITIAL POPULATION

The model handles initial populations of a stock in different locations by assuming a constant stock distribution over that stock's range as discussed in the section on the model. Input to the model contains, for each stock, an initial population, distributed over age, in each location to which that stock is linked.

Initial populations have been estimated using virtual population estimation procedures based on the average catch and escapement of a particular stock in a particular fishing location. The average catch of a stock in a location can be calculated as

$$C(S,L) = C(sp,L) \cdot F(sp,S,L)$$

where $C(S,L)$ = catch of stock S in location L;

$C(sp,L)$ = catch of species sp in location L; and

$F(sp,S,L)$ = fraction of the total number of fish of species sp in location L of stock S,

where F(sp,S,L) is derived from tag-recovery data.[2] The catch of the stock in the location is distributed by age according to the results of location-specific age studies.[3]

The average escapement of a stock attributable to a location can be gotten by

$$E(S,L) = E(S) \times C(S,L) / C(S,LL)$$

where $E(S,L)$ = escapement of the stock attributable to location L;

$E(S)$ = total escapement of stock S;

$C(S,L)$ = catch of stock S in location L; and

$C(S,LL)$ = total catch of stock S in all locations.

This escapement is distributed by age as was the catch.[4] The sum of the catch and escapement is the basis for the virtual population estimate.

If fishing is assumed to take place at the beginning of the year, the virtual population of fish of age A in a location is given by

$$V_A = C_A + C_{A+1}e^{M} + C_{A+2}e^{2M} + \ldots + C_{A+R-1}e^{(R-1)M}$$

$$= \sum_{i=0}^{R} C_{A+i}e^{iM} \qquad (1)$$

[2,3,4] Informal Committee on Chinook and Coho (1969)
Godfrey (1971)
WDF, annual report (1966-1969)
Tanaka (1969)
BC catch statistics (1966-1969)
Killick (1963)
INPFC Statistical Yearbook (1966-1960)
personal communication, Dale Ward, WDF

where V_A = the virtual population of age A fish;

C_A = the average catch + average escapement of age A fish;

M = instantaneous natural mortality rate;

R = maximum age present in the fishery.[5]

If fishing takes place at the end of the year the virtual population is given by

$$V'_A = C_A e^M + \ldots + C_{A+R-1} e^{RM}$$

$$= \sum_{i=0}^{R} C_{A+i} e^{(i+1)M} \qquad (2)$$

For this research it is assumed that fishing operates continuously throughout the year. This necessitates the use of an average population estimate. Since

$$V'_A = \sum_{i=0}^{R} C_{A+1} e^{iM} e^M$$

$$= V_A e^M, \qquad (3)$$

the geometric mean can be used for the virtual population

$$(V'_A \cdot V_A)^{1/2} = (V_A \cdot V_A e^M)^{1/2}$$

$$= V_A e^{1/2M} \qquad (4)$$

---

[5]The inclusion of ages 1 to R is the result of the program GAMES requiring the presence, in all initial feeding locations, of 1 year old fish even though this is generally not the actual situation.

Incorporating all constants and variables the composite virtual population estimate of the numbers of fish of stock S and age A in location L is given by

$$V_A = \sum_{i=0}^{R} (C_T \circ P_S \circ P_{A+i} + E_S \circ \frac{C_S}{C} \circ P_{A+i}) \, e^{(i+1/2)M} \qquad (5)$$

where C_T = total catch of the species in the location;

P_S = proportion of C_T attributable to stock S;

P_A = proportion of catch of age A;

E_S = total escapement of the stock;

C_S = catch of stock S in the location;

C = total catch of stock S in all locations;

M = instantaneous natural mortality rate;

and C_T, E_S, C_S, C and M are assumed known and without variance and P_S and P_A are assumed to be independent random variables.

Computed initial population values by stock, age and location, CENSUS (stock, age, location) can be found in the appendix as part of the listing of the default input.

GROWTH

Growth of individual salmon in the model is specified by an age-specific growth curve. Values for the growth curves are input to the program for specific ages. The program interpolates linearly to get weights of fish of intermediate ages. Growth curve values are listed in table 3.

Fall chinook migrate to the ocean in the spring of their first year of life. The model assumed fall chinook to be 1 year old on the following January 1. Spring chinook migrate to the ocean in the spring during their second year, one year after hatching. The model assumes springs to be 2 years old on the following January 1. Coho migrate to sea at the end of their first year. Chum migrate immediately after hatching. Sockeye are all assumed to be sub 2's, that is, migrate during their second year. These become 3 years old on the following January 1.

In its present form the model does not account for seasonally variable growth.

Growth parameters are input to the program as age, XWEIGH (stock) and weight in metric tons, YWEIGH (stock). These parameters are listed in the appendix as part of the default input.

TABLE 3. Growth curve values for modeled Pacific salmon, Washington Salmon Fisheries Model.[a,b]

SPECIES	PARAMETERS	AGE 1	2	3	4	5
chinook	length (in)	10.0	21.0	28.5	35.0	39.0
fall						
	weight (lb)	.4	4.5	12.2	23.8	33.8
spring	length	4.0	18.0	26.0	33.0	39.0
	weight	.04	2.7	9.0	19.6	31.0
chum	length	-	13.1	17.8	20.8	-
	weight	.25*	.9	2.3	3.8	4.8*
coho	length	2.0	13.0	27.0	-	-
	weight	.25	2.0	10.0	-	-
pink	length	-	-	-	-	-
	weight	.3	6.5	-	-	-
sockeye	length	-	-	19.0	23.7	25.6
	weight	.5*	1.3*	3.1	6.0	7.6

[a]Computed from data. Informal Committee on Chinook and Coho (1969); Killick (1963); Rogers (1972).

[b]Symbols: *= weight interpolated from a fitted curve; -= data point not given or does not exist.

MORTALITY

At various times individual fish are subject to natural, fishing and catch-release mortalities. Natural mortality acts on all fish during all time periods. For this version of the model no attempt was made to impose age-specific natural mortality. Though it is quite certain that natural mortality is age-specific, a literature survey produced no reference to actual values in this form, but only yearly, non-age-specific values. Instantaneous natural mortality rates from various sources are listed in Cleaver (1967). Species-specific natural mortality rates used in this model are listed in table 4.

TABLE 4. Species-specific instantaneous (yearly basis) natural mortality rates for modeled Pacific salmon, Washington Salmon Fisheries Model.[a]

Species	M
chinook	.341
chum	.20
coho	.32
pink	.20
sockeye	.37

[a]adapted from data. Cleaver (1967); Parker (1956).

During the fishing season salmon populations are subject to fishing mortality. The instantaneous fishing mortality rate, F, is computed for each population for each month by the program as

$$F(S,P,mo) = \sum^{H} F(S,H,mo) = \sum^{H} \left(q(S,A) \cdot f(H,mo) \cdot k(H) \right) \quad (6)$$

F(S,P,mo) = instantaneous fishing mortality for stock S, population P, month mo.

q(S,A) = catchability coefficient, stock S, age A

f(H,mo) = fishing effort for harvester H, in month mo.

K(H) = relative fishing efficiency for harvester H

If a fish under the location, harvester and species-specific size limit is caught, it is released. A certain percentage of released fish are lost due to damage by the fishing gear. It is assumed that all net gear is perfectly selective, so that all fish caught are kept and gear damage mortality for net gear is zero. Sport and troll hook gear are assumed to be nonselective; certain fish are returned and are subject to hooking or shaker mortality. Wright (1971) surveys the problem of hooking mortality in the Washington coastal troll fishery at some length and concludes that the loss reasonably lies somewhere between .15 and .35 of the returned salmon and that this proportion varies with age. The model assumes gear and age specific hooking mortality proportions as listed in table 5.

TABLE 5. Hooking mortality proportions for modeled gear and Pacific salmon, Pacific Coast Salmon Fisheries Model.

GEAR	AGE 1	2	3	4	5
sport, troll	0.75	0.5	0.3	0.2	0.2
seine, gill net	0.00	0.0	0.0	0.0	0.0

Instantaneous natural mortality is input as NMORT(stock). Instantaneous fishing mortality is computed by the program using the following input parameters:

QC(stock,age), the catchability coefficient;

EFFDI(harvester, month), harvester effort; and

FPWDI(harvester, stock), relative harvester efficiency.

Parameters affecting hooking mortality are:

SLIMIT(harvester,stock), the minimum size limit;

XHOOK(gear,age), the abscissa (age) for the hooking mortality curve; and

YHOOK(gear,age), the ordinate (mortality) for the hooking mortality curve.

Mortality parameters are tested in the appendix as part of the default input.

MIGRATION

At the beginning of a model year, the program divides each population (i.e. stock in an initial location) into groups of mature and immature fish. As discussed in the description of the model, immature fish remain in the initial locations for the entire model year subject to the depredations of natural and appropriate fishing mortality. Matures remain in initial locations subject to similar mortalities until the time that they leave on spawning migration. During migration mature fish pass through successive fishing areas where they are subject to natural mortality plus area-specific fishing mortality for a period of time proportional to the distance travelled in crossing the area.

To model the migration of a population of mature salmon it is necessary to estimate the values of four parameters for each population. These parameters are:

TMIGR(S), the month in which mature individuals of stock S migrate;

TMGRTN(S), the length, in months, of the migration of stock S;

TESCPT(S), the month in which mature individuals of stock S escape the terminal fisheries; and

MIGRTN(S,P,L), the proportion of the total migration time spent by the migrants of population P of stock S in location L.

The dates of arrival at the mouth of the spawning stream for the species modeled are listed in table 6.

TABLE 6. Dates of arrival at the mouths of spawning streams for modeled Pacific salmon, Washington Salmon Fisheries Model.[a]

SPECIES	TIME OF PEAK ARRIVAL
Chinook	
fall	September 1
spring	May 1
Chum	November 1
Coho	September 1
Pink	October 1
Sockeye	November 1

[a]Calculated from data. Informal Committee on Chinook and Coho (1969); BC Catch Statistics (1970); IPSFC annual report (1961-1969); Korn (1971).

The report of the informal committee, the British Columbia catch statistics and Korn (1971) indicate that a date of September 1 for the time of peak arrival is reasonable for fall chinook stocks spawning in areas from the Columbia River to the Fraser River. Korn (1971) indicates dates of March 15 for peak Spring chinook arrival on the Columbia River and

July 1 for summer chinook. Combining these dates, May 1 will be assumed for the peak arrival of stocks of spring-summer chinook. The assumed dates for peak arrival at the mouth of the spawning stream for coho, chum, pink and sockeye salmon are listed in table 6.

It should be noted that dates of arrival listed in table 6 are the times of arrival at the mouth of the parent stream. For stocks returning to the Columbia and Frasier Rivers where there exist river fisheries, actual escapement occurs after the fish have passed these terminal fisheries. For other areas arrival and escapement are assumed to be concurrent.

The model assumes that, on arriving at the mouth of the parent stream, migrating fish immediately enter and escape the terminal fisheries. Any time spent milling at the stream mouth is ignored, as these fish are generally protected from fishing pressure in these areas.

An estimate of the speed of migration for returning mature salmon was arrived at from several sources. Analysis of tag-recovery data from the Umatilla area of the Washington coast in Kauffman (1951) indicates a rate of migration of 1.77 miles per day for chinook salmon. Also in Kauffman (1951), tagging at Lennard Island, Western Vancouver Island,

indicates a ratio of 2.24 miles per day for coho. MacKay et al. (1943) report that sockeye tagged at Sooke (Straits of Juan deFuca) were recaptured at Pt. Roberts, a distance of 52 miles from the tagging area, after from 6 to 7 days implying a rate of migration of 8 miles per day. Pritchard and Delacy (1944), reporting on the migration of pink salmon, state that an average rate of migration for pink salmon cannot be estimated with certainty. An analysis of their data results in an estimate of 4.8 miles per day.

Given the divergent results of the various studies, the hesitancy of past investigators to specify definite migration rates and the intuitive notion that the largest fish does not swim the slowest, the above estimates have been averaged and for the purposes of this model a migration rate of 4.2 statute miles per day for the mature migrants of all stocks of Pacific salmon is assumed.

Distances covered by migrating fish are listed in table 7. The model assumes that migration begins in the middle of the initial location for chinook and coho. Sockeye, pink and chum migrants are assumed to be migrating through the locations and their transit begins at the

Given a population of a stock (i.e. stock in an initial location), migration parameters are computed as follows:

TABLE 7. Distances through migrating fish areas, Washington Salmon Fisheries Model.[a]

Area and Description	Distance (statute miles)
SE Alaska	
Cape Spencer - Cape Murzon	300
Northern British Columbia	
Dixon Entrance - Cape Scott	300
Eastern Vancouver Island	
Cape Scott - Vancouver	250
Western Vancouver Island	
Cape Scott - Cape Flattery	235
Fraser River	
Mouth through statistical area 29D	47
Northern Puget Sound	
Port Angeles - Pt. Roberts	70
Southern Puget Sound	
Admiralty Inlet - Tacoma Narrows	70
Washington Coast	
Cape Flattery - Cape Disappointment	150
Columbia River	
Mouth - Bonneville Dam	133
Oregon Coast	
Cape Disappointment - California Border	295

[a]Distances from map. National Geographic Society (1950); National Geographic Society (1966).

1) TESCPT, the date of escapement. For populations spawning in the Fraser and Columbia River systems, the date of escapement is the arrival date (table 6), plus the time required to pass the river fisheries. For populations migrating to other areas the escapament date is assumed to be the arrival date.

2) MIGRTN, the proportion of the migration time spent by the population in a location. This is determined by dividing the distance travelled in that location by the rate of migration.

3) TMGRTN, the total time spent in migration. The number of dyas required for a population to complete migration is the sum of the days spent in the various locations.

4) TMIGRS, the date of migration. The date on which the spawning migration begins is figured by subtracting the days in migration from the date of escapement.

It should be noted that each stock is comprised of several populations, each occupying a different location. Since these populations all escape at the same time, it follows that they must start their migrations at different times. The program requires all populations of a stock to begin migrating at the same time. This inconsistency is resolved by extending the

proportion of migration time spent in the initial location for populations migrating shorter distances.

Other input parameters controlling migration are:

FRCTNM(stock,age), the percentage of the age group that is mature;

DIRCTN(stock), the direction of the spawning migration;

TESCPT(stock), the month of escapement;

LOCTRG(stock), the target (spawning) location; and

E(stock,age), initial escapement for use in model year 1 before computed escapement is effective.

Migration parameters are listed in the appendix as part of the default input.

SPAWNER-RECRUIT

Spawner-recruit relations are specified by Beverton- and Holt-type equations (Ricker, 1958).

$$R = \frac{S}{A + B\,S} \qquad (7)$$

where R = number of recruits to the stock resulting from

S = the number of spawners where

A = a regression parameter and

B = another regression parameter.

The escapement, E, of a stock is composed of fish of several ages, each with a characteristic fecundity. The components of E are multiplied by age and species-specific fecundity factors and become S, the "standardized" number of spawners. Spawners are converted to recruits, R, by a species-specific spawner-recruit equation. R is then multiplied by a normal random variate, N, with mean 1 and variance, σ^2, equal to the variance about the spawner-recruit curve relative to the asymptotic number of recruits.

$$R' = R\ N(1,\sigma^2) \qquad (8)$$

This gives a recruit class, R', adjusted for environmental conditions.

At this stage of the model, one spawner-recruit curve is used for all stocks of a species. This is justified by the lack of complete escapement-return data for the majority of stocks considered and by the fact that the variances used in the random multipliers, N, are so large that almost all environmental variability is encompassed in the resulting R'.

Spawner-recruit parameters A and B were estimated using two nonlinear regression programs NLIN and NONLIN (Hamerly, 1972; Wilcoxson, 1969). Initial estimates for the nonlinear regressions were calculated using linear regression program FR 312 (Dahlberg, 1968). Results of the nonlinear regression are listed in table 8.

TABLE 8. Spawner-recruit parameters for modeled species, Pacific Coast Salmon Fisheries Model. Estimation by nonlinear regression.

SPECIES	A	B	σ
chinook			
fall	.1093	1.235×10^{-5}	2.17×10^{5}
spring	.0100	2.62×10^{-6}	1.7×10^{4}
chum	.0048	5.42×10^{-20}	4.2×10^{4}
coho	.0019	3.14×10^{-5}	4.823×10^{3}
pink	.222	3.29×10^{-4}	1.1×10^{2}
sockeye	.0236	4.92×10^{-6}	2.77×10^{4}

Fall chinook escape-return data for years 1938 through 1970 for the Columbia River are taken from Korn (1971). Return figures are minimum and are the sum of escapement above Bonneville Dam, known hatchery escapement below Bonneville and the Columbia River commercial catch. Estimated escapements combine

Bonneville Dam and known hatchery escapements. Escape-return data for chum, coho, pink and sockeye salmon are from Bulletin 10, International North Pacific Fisheries Commission. Chum and coho are for Minter Creek, Washington stocks, 1936 to 1954. Pink salmon data are for stocks from Puget Sound and adjacent areas, 1919 to 1955. Sockeye data are for Columbia River stocks, 1934 to 1952.

Spring chinook escape-return data are from Korn (1971). Due to inadequate spring chinook data for low values of S the nonlinear regression failed to converge to realistic parameter values for this species. Since

$$R = \frac{1}{B + \frac{A}{S}}$$

and $\lim_{S \to \infty} R = \frac{1}{B}$, (10)

the data suggests that a near-constant recruitment is more appropriate in this case. So $\frac{1}{B}$, the asymptotic recruitment, is set equal to the mean of the recruitment values. Under the assumption that .9 of the asymptotic recruitment is reached by 10^5 spawners, a value of A is calculated (.01). This assumption is consistent with, but not suggested by the data. By manipulation of the program NLIN, an estimate of the variance of B was calculated.

Input parameters describing spawner-recruit relations and recruitment are:

BEVER(stock), the spawner-recruit equation;

SIGMA(stock), the standard deviation around the spawner-recruit curve relative to the asymptotic recruitment;

TRECRT(stock), the month of recruitment; and

PERC(stock,location), the fraction of the total derived recruitment to be delivered to a particular location.

These parameters are listed in the appendix as part of the default input.

PARAMETER ESTIMATION-HARVESTER SECTOR

The model's concern with harvester activities is limited to the number of units of gear operating in a location and their average trip time, days-per-month spent fishing and fishing power relative to a base gear type. Harvester economics considers fixed cost and direct operating costs per day and per ton of catch.

EFFORT

In the model a harvester is a fleet consisting of boats of one gear type operating in one fishing location.

The program base allows for variable harvester effort by month. To compute the monthly effort the following assumptions are made.

1) Model gear is licensed to fish in only one model location;
2) Catch is proportional to effort; and
3) All gear licensed in a location fishes during the month corresponding to the maximum catch in that location.

U.S. fishing effort is published as the number of boat licenses issued. Using assumptions 2 and 3, effort in a location is distributed by month according to the proportion

$$\frac{\text{Catch(month)}}{\text{Catch(month of greatest catch)}} .$$

The computation are straightforward for Southeastern Alaska trollers (statistical areas 104, 113, 114), Washington coastal trollers, Columbia River gill netters and Oregon trollers.[6]

For Puget Sound purse seine and gill net fisheries, statistics are published for the entire area inside Cape Flattery. As stated previously, the model considers two fishing locations in this area, northern Puget Sound (those waters inside Cape Flattery and north of Admiralty Inlet) and southern Puget Sound. To distribute Puget Sound effort between these areas, an average catch distribution between the two locations was computed, weighted both by year and species.[7] This computation indicated that .893 of the Puget Sound catch of all species resulted from northern Puget Sound fisheries. Given the number of licenses issued, monthly effort for the model harvesters was calculated in the way described previously.[8]

Canadian effort by month and fishing location is published as the total days spent fishing. This was converted to the number of boats fishing per month in a location by total days by dividing the average number of days per month spent fishing by a boat of that gear type, as given in Newton (1972).[9]

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[6] INPFC statistical yearbook (1964-1969)

[7] Personal communications, Dale Ward, WDF.

[8] INPFC statistical yearbook (1964-1969)

[9] BC catch statistics (1964-1969)

The unit of effort for the sport fisheries is the angler-day. Sport effort is based on the average number of salmon caught per angler-day for various fishing locations as published in Newton (1972) and listed in table 9.

TABLE 9. Catch per angler-day by fishing location, modeled sport salmon fisheries, Washington Salmon Fisheries Model.

LOCATION	C/f
Puget Sound	.379
Washington coast	1.531
Columbia River	1.455

To compute sport effort the following assumptions are made:

1) The sport fishing seasons in southeastern Alaska and western Vancouver Island are the same as the commercial troll seasons in those locations;
2) The sport seasons in eastern Vancouver Island and the Fraser River are as the sport season in Puget Sound;
3) Sport catch/effort for S.E. Alaska, W. Vancouver Island and the Oregon coast is the same as that for the Washington coast; and

4) Sport catch/effort for E. Vancouver Island and the Fraser River is the same as that for Puget Sound.

Sport fisheries statistics are published as total catch per year.[10] For each location the sport catch is divided by the C/f for that location giving the total number of angler-days per year fished in that location. Total angler-days are distributed over the fishing season by multiplying angler-days by the fraction of the total commercial catch caught in particular months. Angler-days per month is then divided by four, giving the number of sport fishermen fishing in that month in that location. The assumption here is that the number of days spent fishing per month by the average angler is 4.

Because of the number of individual parameters involved, it is impractical to list in this section the effort by month for the 27 model harvesters. A complete listing can be found in the appendix as part of the default input. Effort input is listed as EFFDI(harvester).

Days per month spent fishing for commercial gear is taken from Newton (1972). Newton's figures are for the Washington fisheries. Assuming that fishermen using similar gear will adopt similar fishing strategies,

[10] Informal Committee on Chinook and Coho (1969); BC Catch statistics (1966-1969)

The Washington days-per-month figures are used for model commercial gear in all model locations.

Newton uses a figure of 12.5 days per month spent fishing for sport fishermen. As this seems unreasonable the model assumes a figure of 4 days per month. This assumption is based on the notion that a sport salmon fisherman would, on the average, spend one day per weekend fishing. The assumption ignores increasing availability of fish, increasing leisure time and better weather as the season progresses and the resultant increasing desire to fish. The probable situation of low early and late individual effort per month and high individual effort in mid-season (summer) is approximated by the assumption of a constant 4 days per month fishing for all sport salmon fishermen.

Days per month fished are listed in table 10.

TABLE 10. Days per month spent fishing by modeled gear, Washington Salmon Fisheries Model.

GEAR	DAYS/MONTH
gill net	12.5
purse seine	16.7
sport	4.0
troll	14.3

The model assumed a trip time of one day for all model harvesters. The number of days per month fishing is input as HDELI(harvester). Trip time is input as DYSTRP(harvester).

Gear efficiency relative to gill net is taken from Newton (1972) and Royce et al. (1963) and listed in table 11.

TABLE 11. Gear efficiency relative to gill net for modeled gear, Washington Salmon Fisheries Model.[a]

	SPECIES				
GEAR	CHINOOK	CHUM	COHO	PINK	SOCKEYE
gill net	1.0	1.0	1.0	1.0	1.0
purse seine	2.9	3.5	2.9	11.6	7.0
sport	0.02	-	0.01	-	-
troll	1.0	-	1.0	0.5	-

[a]Symbol: -= this species is not normally taken by this gear

Newton gives sport efficiencies by month. Apparently he keeps sport effort constant and varies efficiency. It seems more reasonable to do the converse and in this model an average figure for efficiency has been used with variable effort.

Relative fishing power is input as the parameter FPWDI(harvester).

ECONOMICS

Values for harvester economic parameters are taken directly from Newton (1972). Fixed costs are those incurred by the harvester regardless of time spent fishing and the size of the catch. Fixed costs are input as the parameter HFXDXP(harvester) and are computed for the entire fleet of a harvester as cost/month. Direct operating and harvesting expenses are those incurred as the result of operation and harvesting effort and are proportional to the levels of these activities. Operating cost per day is input as HVRCPE(harvester). Harvesting cost per ton of catch is input as HRCOST(harvester). Harvester economic values are listed in the appendix as part of the default input.

Traditional economic evaluation of sport fisheries have tended to place a value on sport-caught fish in excess of the commercial value, a value supposedly reflecting the value of recreation. Fixed expenses for sports fishermen are regularly ignored. Therefore in this model it is assumed that the recreational value of sport fishing exactly offsets sport fishing fixed costs and both are set equal to zero. Operating and harvesting expenses for the sport fisheries are conceded to be zero. By these assumptions no attempt is made to attach social values to sport and

commercial fisheries. The model responses of sport and commercial harvesters are evaluated separately in terms of catch and net revenue. The problem of comparative value is not addressed.

PARAMETER ESTIMATION-REGULATOR SECTOR

Harvesters are regulated in the various locations by varying the fishing season and minimum size limit. Fishing season is regulated monthly by varying the parameter RDELT(harvester), the number of days that can be fished in that month by that harvester. Size limit is regulated yearly by the parameter SLIMIT(harvester,stock), an input to the stock sector.

GAMES has provisions to allow setting annual catch quota, and effort and efficiency limits for the harvesters. Unfortunately, in this version of the program it is a programming impossibility to implement these features. Annual catch quotas for the sport fisheries, assuming a four day per month fishery, would be the only realistic use of these features, since harvester efficiencies and effort levels are set.

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Literature Cited

Cleaver, F. C. 1969. Effects of ocean fishing on 1961 brood fall chinook salmon from Columbia River hatcheries. Res. Rep. Vol. 1, no. 1. Fish Comm. of Ore., 307 State Office Bldg., Portland, Ore. 97201. 76 p.

Dahlberg, M. L. 1968. Linear regression. program FRD 312. Fish. Anal. Cent., Fish. Res. Inst., Coll. of Fish. Univ. Wash., Seattle, Wash. 98195. 10 p.

Department of the Environment, Fisheries Service, Pacific Region. 1966 to 1969. British Columbia catch statistics. Vancouver 1, B.C., Canada.

Gales, L. E. 1972. Salmon Games: an interactive salmon stock management game. Quant. Sci. paper no. 3. Center for Quant. Sci., Univ. Wash., Seattle, Wash. 98195. 25 p.

Godfrey, H. 1971. Contribution of 1966 brood coho salmon from US hatcheries to US and Canadian fisheries in 1969. Tenth annual progress rep. Manuscript rep. ser. no. 1153. Fish. Res. Board Can., Ottawa, Canada 16 p.

Hamerly, E. R. 1972. Parameter estimation made easy. Coniferous Forest Biome, IBP, Univ. Wash., Seattle, Wash. 98195. (Unpub. MS). 20 p.

Informal Committee on Chinook and Coho. 1969. Reports by the United States and Canada on the status, ocean migrations and exploitation of northeast Pacific stocks of chinook and coho salmon, to 1964. (Unpub. MS). 2 vol.

International North Pacific Fisheries Commission. 1961 to 1969. Statistical Yearbook. Vancouver 8, B.C., Canada.

International Pacific Salmon Fisheries Commission. 1961 to 1969. Annual report. New Westminster, Can.

Killick, S., W. Clemens. 1963. The age, sex ratio and size of Fraser R. sockeye salmon, 1915 to 1960. Bull. 14. Int. Pac. Salmon Fish. Comm. New Westminster, B.C., Canada. 139 p.

Korn, L. 1971. Information on Columbia River salmon runs and fisheries. Fish Comm. of Ore. Rep. for Int. Pac. Fisheries Comm. State Office Bldg., Portland, Ore. 97201. (Unpub. MS). 32 p.

National Geographic Society. 1950. Northwestern United States. Map, 1:2,500,000. Wash., D.C.

National Geographic Society. 1966. Western Canada. Map, 1:5,068,800. Wash., D.C.

Newton, J. D. 1972. The Washington state salmon fisheries: a simulation study. Doctoral dissertation. Univ. Wash., Seattle, Wash. 98195. 200 p.

Parker, R., W. Kirkness. 1956. King salmon and the ocean troll fishery of southeastern Alaska. Res. rep. no.1. Alaska Dep. of Fish., Juneau, Alaska. 64 p.

Ricker, W. E. 1958. Handbook of computations for biological statistics of fish populations. Bull. 119. Fish. Res. Board of Canada. Ottawa, Canada. 300 p.

Rogers, D. E. 1972. Forecast of the sockeye salmon run to Bristol Bay in 1972. Circ. no. 72-73. Coll. of Fish. Univ. Wash., Seattle, Wash. 98195.

Royce, W. F., D. E. Bevan, J. A. Crutchfield, G. J. Paulik, and R. L. Fletcher. 1963. Salmon gear limitation in northern Washington waters, p. 1-123. In Pub. In Fisheries, New Ser., vol. 2. Univ. Wash., Seattle. 98195.

Washington Department of Fisheries. 1966 to 1969. Annual report. State Printing Plant, Olympia, Wash. 98504.

Wilcoxson, W. L. 1969. A specialized non-linear least squares program: NONLIN. program FRG 717. Fish. Anal. Cent., Fish. Res. Inst., Coll. of Fish., Univ. Wash., Seattle, Wash. 98195. 10 p.

Wright, S. 1971. A review of the subject of hooking mortalities in Pacific salmon (Onchorhynchus). Wash. Dep. of Fisheries, Manage. and Res. Div. Rep. for Pacific Marine Fisheries Comm. Olympia, Wash. 98504. (Unpub. MS). 40 p.