CFM Sim

Constant Fractional Marking Simulation Program

Program Manual

Version 1.0

For Windows

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[1]**Prepared for**: Bailey Environmental under University of Idaho Budget ARK787.

List of Tables

Preface

License

This program is to be used solely for the purpose of analyzing the four marking alternatives (denoted NS1, NS2, S1, S2) described in the program manual. The suppliers of CFM Sim are not responsible for the results obtained from this program to analyze modified alternatives. It is the sole responsibility of the user to determine that the data entry is reasonable and correct, and their analysis of the output is sound. The suppliers of CFM Sim are not responsible for misinterpretation of results or incorrect data entry.

System Requirements

CFM Sim will run on a PC-Compatible computer running Windows 95, 98, or NT 4.0. A minimum processor speed of 166MHz and 32MB of memory is recommended. The program has not been tested with Windows 2000.

Installation

CFM Sim is distributed on three 1.44MB floppy disks or as a zipped file which can be downloaded from `http://www.uidaho.edu/~newman/CFM/index.html`.

Installing from the floppy disks. To install CFM Sim from the floppy disks, either double-click the program called **setup.exe** or type **a:\setup.exe** in the command line of the run dialog box, found in the Start menu. This will invoke the setup process which will guide you through the rest of the installation. The default setup values should work in most cases.

Installing from the downloaded file. When installing from the downloaded file, you must first unzip the file. This will create a folder called CFM Sim which contains the necessary setup files, a read me file, and this program manual in pdf format. Double-click the program called **setup.exe** to begin the installation process. You will be guided through the installation which has commonly used setup values set as default. Files necessary for the operation of CFM Sim are installed in the appropriate places during the setup process.

CFM Sim can then be started by selecting the icon placed in the Programs folder of the Start menu, or opening the file called **CFM Sim.exe** which was installed in the directory chosen in the setup process (most commonly `‘‘C:\Program Files\CFM Sim’’`).

After installing CFM Sim, the program may be uninstalled using the Add/Remove Programs program found in the **Control Panels** folder. If prompted to delete certain files, be absolutely certain that they are not necessary before deleting them. If unsure, it will not affect the system to leave them.

Program Manual Conventions, Notation, and Definitions

Table 1 refers to the typefaces and symbolds used to indicate special text in this manual.

Table 1: Typefaces and symbols used to indicate special text.

Typeface or symbol	Meaning
Bold	Bold typeface denotes a parameter.
Bold Italics	Bold Italics represents a file that is written to disk or accentuates a concept that must be understood.
Emphasized	Emphasized words refer to a sheet in the workbook, a menu at the top of the program, or a command within a menu.
Sans serif	Sans serif refers to a key to press on the keyboard. For example, Esc would refer to the Escape key on the upper left of the keyboard.

Certain words are used when describing the program's operation and need to be defined.

Stock Fish from the same watershed or hatchery, that experience the same survival, harvest, maturation, and other life history parameters.

Recruitment The number of newly emerged progeny of last year's spawning females. These fish will next experience initial survival in their sequence of life history events.

Watershed An inland section of the river where fish may spawn.

In-river Escapement The number of fish that pass the terminal fishery of a watershed and spawn naturally in that watershed.

In-hatchery Escapement The number of fish that pass the terminal fishery of a watershed and are taken by the hatchery in that watershed.

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Thank you to Randy Bailey for all the answers to any question about salmon life history. His patience and generosity are highly valued. Also, many thanks to Bailey Environmental for the funding provided during the development of CFM Sim.

Many other people contributed to the development of CFM Sim. Dr. David Hankin and Dr. Lyman McDonald contributed many ideas initially, as well as reviewed the initial report written by Dr. Ken Newman (Newman 2000). Bruce Bolden gave simple answers to the programming questions I had. Finally, Dave Fournier supplied me with AD Model Builder, although I did not need to use optimization procedures in the end.

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Overview of CFM Sim

1 Intended uses of CFM Sim

Constant fractional marking is an idea put forth by Hankin (1982) whereby a fixed percentage, say 30%, of groups of juvenile hatchery salmon are marked, usually by the removal of the adipose fin, year after year prior to release from a hatchery. When these fish return from the ocean to the originating watershed, the number of hatchery fish in the escapement can be estimated by simply dividing the number of marked fish by the marking rate. This estimate of hatchery fish can be subtracted from the total escapement estimate to provide an estimate of the escapement of unmarked natural or wild fish.

For example, suppose 30% of all juvenile hatchery chinook salmon were marked at least 4 years in a row. Assume that all fish mature by age 5. In the fifth year a sample of 1,000 fish is taken from the chinook salmon return and 200 marked fish are in the sample. The estimated number of hatchery fish in the sample is 200/0.3 = 667; thus the number of natural fish is estimated to be 333, or 33.3% of the return.

The primary reason for developing CFM Sim was to provide a tool for fisheries biologists and biometricians to study the effects of changing different constant fractional marking rates on the quality of estimates of production, where *production is the sum of escapement and fishing mortality (including incidental fishing mortality, such as hooked but not landed).* CFM Sim can be used to examine the difference in the accuracy of estimates of production between a 20% CFM rate and a 40% CFM rate.

There are many other factors besides the CFM rate that affect the quality of production estimates. Some of these factors are the sampling rates of catches in the marine fisheries, sampling rates of catches in the freshwater fisheries, and sampling rates of the escapement to the spawning grounds and to the hatchery. Marine survival rates, fishing harvest rates, and maturation rates also have an effect. The user of CFM Sim can manipulate all these factors in addition to the CFM rate to try to understand the effects of these factors as well.

A secondary reason for developing CFM Sim, which arose in the course of developing the statistical estimation procedures (Newman 2000), was to develop a tool for analyzing the effect of selective fisheries, fisheries which aim to catch only externally marked hatchery fish, on the escapement of natural stocks. Selective fisheries will unintentionally kill the unmarked natural fish both by hooking, but not landing such fish (so-called drop-off mortality) and by hooking, landing and then releasing such fish (so-called shaker mortality). One of the options of CFM Sim is to simulate the presence of a selective marine fishery. CFM Sim is unrealistic in that only shaker mortality is simulated. However, the user can study the consequences of changes in shaker mortality rates on the subsequent escapement of a natural stock.

2 What CFM Sim does

CFM Sim is a computer program that simulates the process of juvenile chinook salmon leaving different watersheds of the Sacramento river system and subsequently experiencing the processes of natural mortality, fishing mortality, and maturation. The catch of fish harvested in marine or freshwater fisheries is sampled for recoveries of marked and/or tagged fish. Similarly the escapements of fish to different watersheds are sampled for marked and/or tagged fish.

The sample data are then input to a statistical procedure that yields estimates of the production of natural and hatchery fish for different watersheds. Production is defined as the sum of landed catch and escapement for a given stock of fish, either hatchery or natural, in a given year.

The estimates of production are then compared to the "true" production values. The measure of comparison is the mean relative absolute error, labeled MAE. To calculate the MAE for a given stock, the relative absolute error, |Estimate - Truth|/Truth, is calculated for each simulated year and then averaged across all the years of simulation. For example suppose just 2 years were simulated. The true production was 10,000 and 11,000 for both years and the corresponding estimates were 9,500 and 11,200. Then

$$\begin{aligned} MAE &= \frac{1}{2}\left(\frac{|9,500-10,000|}{10,000}+\frac{|11,200-11,000|}{11,000}\right) \\ &= \frac{1}{2}(0.05+0.018)=0.034 \end{aligned}$$

or a 3.4% relative absolute error.

The user can carry out different sets of simulations to compare the effect of changes in CFM rate, say, on the MAE for a particular stock. For example, 100 simulations of with a 20% CFM rate are run and the MAE is 22%. Another 100 simulations using a 40% CFM rate are, with all other factors kept the same (and perhaps using the same random number seed), and the MAE is 16%. Thus the effect of changing from a 20 to 40% CFM rate is estimated to be a 6% decrease in the MAE.

3 Four categories of simulations

The statistical procedures that are the heart of CFM Sim arose from meetings during 1999 of individuals involved with the CAMP (Comprehensive Assessment and Monitoring Program) and CALFED projects. At these meetings various procedures for marking and tagging hatchery fish and associated procedures for using sample recoveries of these fish to estimate production of natural fish were discussed. One issue that became apparent was the effect that selective fisheries would have on both the marking and tagging procedures and on the estimation procedures compared to non-selective fisheries.

It turned out that due to the number of watersheds in the Sacramento river system the CFM procedure was modified in that while the constant fraction marked would be the same for all watersheds, uniquely coded coded-wire-tags would be placed in all the "CFM" fish. One issue that arose was the merit of externally marking all (or nearly all) hatchery fish, i.e. the remaining "non-CFM" fish would get an external mark versus just marking and tagging a constant fraction with the remainder receiving no mark nor tag.

From these two issues, selective fisheries and complete marking of hatchery fish, four marking and tagging alternatives were developed. These had been labeled alternatives 5 through 8 in Newman (2000). We have relabeled these alternatives using more informative labels. The old and new labeling along with a brief description of the marking and tagging procedures are listed here.

Former Label	Current **Label**	**Description**
#5	NS1	Non-selective fisheries, a fraction of each hatchery release is marked and tagged, the remainder are marked
#6	NS2	Non-selective fisheries, a fraction of each hatchery release is marked and tagged, the remainder are unmarked and untagged
#7	S1	Selective fisheries, a fraction of each hatchery release is marked and tagged, the remainder are marked
#8	S2	Selective fisheries, a fraction of each hatchery release is marked and tagged, the remainder are unmarked and untagged

The descriptions are not entirely accurate in that portions of hatchery releases, labeled *ad hoc*, *surrogate*, and *stealth*, are dealt with differently. Details of the differences are discussed in the appendices of the manual.

For any given set of simulations, the user selects one of the above four categories. The majority of input parameters are the same for each category but there are some additional parameters that must be specified for selective fisheries, in particular, and these are noted in the next section.

4 Annotated listing of input parameters

The user enters data on three separate worksheets, labeled *Globals*, *Hatchery*, and *Natural*. The *Globals* sheet contains parameters that affect all stocks, or all of the fish in a particular watershed, for example ocean fishing mortality and catch sampling rates. The *Hatchery* and *Natural* sheets contain parameters that are particular to a particular stock, such as marine survival and maturation rates. A separate tutorial document has been prepared that steps through the data entry procedure for a particular example of NS1. Each of the input parameters by sheet are briefly tabulated and described in the approximate order they are found on each sheet.

There are a very large number of parameters for which the user must specify values. Some of the values, such as CFM rate or catch sampling rates, are under human control and could vary from 0 to 100%, and the user will often select hypothetical values in order to study the affect of changes in such parameters on MAE, for example. Other parameters are biological, such as survival from time of release to age 2, and the user should exercise professional knowledge to specify what he thinks is a reasonable range of values. For less experienced users a range of input values are listed. The sources for these values include Cramer (undated), Hankin (1990), Hankin and Healey (1986), Hankin and Mohr (1991), and Healey (1991). Some of these values should be viewed skeptically in that data and estimation procedures are inadequate (see, e.g., p. 375 of Healey (1991) and his discussion of estimating maturation rates). In the case of maturation, survival, and harvest rates it is often difficult to disentangle one rate from the other, i.e., the estimates based on tag recoveries are confounded with each other. Frequently analysts of tag data assume known values for one or more parameters in order to estimate another parameter; e.g. in theoretical work, Hankin and Healey (1986), assume that survival rates between years are known in order to estimate maturation rates.

Users more experienced with the analysis of chinook salmon data will want to exercise their own professional knowledge in choosing particular values. The values entered in the tables below are in many cases best guesses as to reasonable values, so the user should not view the listed values as constraints.

4.1 Fishing mortality rates

The fishing mortality rates parameters require explanation. When fishing gear is placed in the water some fish will be caught temporarily by the gear and then escape before the gear is brought in. When the gear is a hook, the percentage of fish that then die after escaping is referred to as drop-off mortality. Mortality is experienced when fish that have been caught are deliberately returned to the water, because the fish is undersize for example. This mortality is sometimes called shaker mortality or hook-and-release mortality (Lawson and Sampson 1996). The incidental fishing mortality rates are complicated by the nature of the gear, the size of the fish, and the age of the fish and CFM Sim greatly oversimplifies these processes by using simply an age-specific overall fishing mortality rate.

In CFM Sim the specification of the fishing mortality rate differs between non-selective and selective fisheries. In the case of non-selective fisheries, NS1 and NS2, the user should specify a fishing mortality rate that reflects caught but not landed fish, caught and retained fish, and caught and returned fish. For NS1 and NS2, CFM Sim is not realistic in that all fish experiencing fishing mortality are labelled catch and this total is sampled. In practice only the caught and retained fish would be sampled.

For the selective fisheries cases, S1 and S2, CFM Sim allows the user to specify a shaker mortality rate separate from the fishing mortality rate. Fishing mortality rate in this case should then be the sum of just "drop-off" mortality and harvest rates. CFM Sim is unrealistic here as well in that the drop-off mortality is lumped into catch and sampled; on the other hand the shaker mortality is not *included in the catch.*

In terms of selecting values for drop-off mortality and shaker mortality rates to add to harvest rates, Lawson and Sampson (1996) report estimates of shaker mortality for chinook salmon ranging from 9 to 30% and state that little is known about drop-off mortality rates. Drop-off mortality can be viewed as the product of the probability of a fish being "hooked" and dropping off and the subsequent probability of dying. The probability of being "hooked" should then be a function of the fishing effort. Lawson and Sampson report estimates of the probability of being hooked and dropping off from 33 to 42%, but only state that the probability of such fish dying should be less than shaker mortality. An unpublished, undated report with no listing of authors to PSMFC, Pacific States Marine Fisheries Commission, (PFMC Ad Hoc Salmon Policy Committee?) listed shaker (hooking mortality) rates ranging from 17% to 64%.

4.2 Globals sheet

Table 4.2 lists all the parameters input to the Globals sheet as well as some possible values for most of the parameters.

If the user specifies a particular Seed value, then others can duplicate the users results (assuming all other parameters are left the same).

Errors in the aging of the fish in catch or escapement samples can also be introduced for each age class by selecting Aging Errors from *Edit* in the top menu bar.

4.3 Hatchery sheet

The parameters for each hatchery stock are entered on separate rows, the columns of which are listed in Tables 4.3 and 4.3.

The survival and maturation values are user specified, but some example values thought reasonable are listed. The range of values could be considerably larger and the user needs to know what is reasonable.

* **% Hatchery Fish Escaped To Hatchery** Given that a native or stray hatchery fish has reached the watershed selected for this row, this parameter is the probability (in percent) that the hatchery fish will escape to the hatchery present in this watershed. 100 minus this value is the probability it will escape to natural spawning areas of this watershed. This parameter is specific to the watershed named in this row and applies to any hatchery fish escaping to the watershed, regardless of stock.

** **% Natural Fish Escaped to Hatchery** Given that a native natural fish has reached the watershed selected in this row, this parameter is the probability (in percent) that the natural fish will escape to the hatchery present in this watershed. 100 minus this value is the probability it will escape to natural spawning areas of this watershed. This parameter is specific to the watershed named in this row.

Table 2: Input parameters for Globals Sheet. The column labeled Values contains a range of historical estimates. "Catch" or "Harvest" includes all fishing induced mortalities, landed or not.

Parameter	**Cell**	**Definition**	**Values**
CFM Rate	B1	% of fish in each hatchery release marked & tagged	Any %'s
Sampling Rate of Total Ocean Catch	B3	% of ocean catch sampled (assumes simple random sample)	20-25%[1]
Sampling Rate of Ocean Sport Catch	B4	% of ocean sport catch sampled	20-25%[1]
% of Total Ocean Catch from Sport Fishery	B5	% of ocean catch due to sport fishery	15-35%[2]
Mainstem Harvest Sampling Rate	B7	% of mainstem catch sampled	10-20%[3]
In-River Escapement Sampling Rate	B10-O10	% of escapement sampled per watershed (follows terminal harvest)	1-27%[4]
In-Hatchery Escapement Sampling Rate	B13-O13	% of hatchery return sampled per watershed (follows terminal harvest)	90-100%[5]
Terminal Harvest Sampling Rate	B15-O15	% of terminal area catch sampled (per watershed)	10-20%[3]
Age 2 Terminal Fishing Mortality Rate	B17-O17 B18-018 B19-O19	min: Lower bound (per watershed) mode: Common value max: Upper bound	10%[6] 12-30%[6] 30-80%[6]
Ages 3-5 Terminal Fishing Mortality Rate	B20-O17 to B28-O28	As for age 2 fishing[6]	
Ocean Incidental Mortality Rate	B31-E31	% Shaker mortality by age (S1 and S2)	9-64%[7]
Mainstem Incidental Mortality Rate	B31-E31	% Shaker mortality by age (S1 and S2)	9-64%[7]
Terminal Incidental Mortality Rate	B31-E31	% Shaker mortality by age (S1 and S2)	9-64%[7]
Aging Sampling Rate	B35	% of any Sample Aged	25-100%[3]
Number of Simulations	B37		Integer ≥ 1
Number of Years	B38	Years within a simulation	Integer ≥ 1
Seed	B39	Initial random number seed	Integer > 1
S-R Model	E2	Spawner-recruit model	4 choices
Percent CV	E4	% variation around S-R curve	25-50%[3]

[1] Based on the range of expansion factors for coded-wire tag recoveries in the Pacific States Marine Fisheries Commission's coded-wire tag data base.

[2] Based on recoveries of Sacramento fall chinook salmon coded-wire tags between 1979 and 1995; source PSMFC RMIS database.

[3] A wild guess.

[4] From Cramer Tables 5 and 6. The values are the range of percentage of carcasses examined relative to the number of river spawners for American River (1976-1987) and Feather River (1977-1988).

[5] From Cramer p. 15- "all returning fish were examined for Ad clips…".

[6] From Cramer Tables 5 and 6. The values cover the range of estimated harvest rates for American River (1976-1987) and Feather River (1977-1988). There was no age-specific information reported.

[7] From Lawson and Sampson (1996) and unpublished report to PSFMC.

Table 3: Part I. Input parameters for Hatchery Sheet. Auto. calc. = automatically calculated.

Parameter	**Column**	**Definition**	**Values**
Stock Name	A	Example: Merced fall chinook	Alphanumeric
Watershed	B	Am. River - Yuba	Menu choice
Total Release	C	# Juvenile Fish released	Any integer[1]
Ad Hoc Release	D	Arbitrary # in Release that are not surrogates nor CFM related	Any #[2] $\leq$ Total-E-H
Surrogate Release	E	# in Release representing a natural stock	Any # $\leq$ Total-D-H
CFM Release	F	# marked & tagged	Auto. calc.
Remaining Release	G	Total-D-E-F	Auto. calc.
Stealth Release	H	# Tagged only (S1 or S2 case)	Any # $\leq$ Total-D-E
Survival Initial	I	min: Lower bound, survival smolt to 2	0.3-1%[3]
	J	mode: Common value	2-4%[3]
	K	max: Upper bound	7-8%[3]
Survival Age 3	L	min: Lower bound, survival 2 to 3	17%[4]
	M	mode: Common value	50%[4]
	N	max: Upper bound	80%[4]
Survival Age 4	O	min: Lower bound, survival 3 to 4	19%[4]
	P	mode: Common value	60%[4]
	Q	max: Upper bound	90%[4]
Survival Age 5	R	min: Lower bound, survival 4 to 5	40%[4]
	S	mode: Common value	90%[4]
	T	max: Upper bound	95%[4]

[1] In Table 1 of Hankin (1999) are listed production goals for the five large-scale chinook salmon hatcheries in the Sacramento River system; e.g. 3.25 million fall chinook smolts for Mokelumne River hatchery.

[2] Example: (Hankin 1999) Coleman National Fish Hatchery tagged 8% of its 12 million fall chinook smolts (brood year 1997) or 960,000. This number could continue to be tagged and released independent of the number of surrogates and CFM groups.

[3] Cramer Table 32.

[4] Crudely rounded minimum, average, and maximum values from Hankin and Mohr (1991) for Klamath River fall chinook.

Table 4: Part II. Input parameters for Hatchery Sheet. Auto. calc. = automatically calculated.

Parameter	**Column**	**Definition**	**Values**
Ocean Fishing	U	min: Lower bound	0-0.5%[5]
Mortality Age 2	V	mode: Common value	4-5%[5]
	W	max: Upper bound	8-9%[5]
Ocean Fishing	X	min: Lower bound	15%[5]
Mortality Age 3	Y	mode: Common value	30-60%[5]
	Z	max: Upper bound	70-80%[5]
Ocean Fishing	AA	min: Lower bound	20%[5]
Mortality Age 4	AB	mode: Common value	40-60%[5]
	AC	max: Upper bound	70-85%[5]
Ocean Fishing Mortality	AD	min: Lower bound	20%[6]
Age 5	AE	mode: Common value	40-60%[6]
	AF	max: Upper bound	70-85%[6]
Mainstem Fishing Mortality	AG,AJ,AM,AP	min: Lower bound	10%[7]
Ages 2-5	AH,AK,AN,AQ	mode: Common value	12-30%[7]
	AI,AL,AO,AR	max: Upper bound	30-80%[7]
Maturity Rate	AS	min: Lower bound	0%[8]
Age 2	AT	mode: Common value	5%[8]
	AU	max: Upper bound	13-30%[8]
Maturity Rate	AV	min: Lower bound	30%[9]
Age 3	AW	mode: Common value	50%[9]
	AX	max: Upper bound	70-80%[9]
Maturity Rate	AY	min: Lower bound	85%[10]
Age 4	AZ	mode: Common value	95%[10]
	BA	max: Upper bound	99-100%[10]
Maturity Rate Age 5	BB	Maturation for age 5	Fixed=100%
Stray Rate	BC-BP	% to each watershed (sums to 100)	0-90%[11]
% Hatchery Fish Escaped to Hatchery	BQ	* see section 4.3	80-90%[12]
% Natural Fish Escaped to Hatchery	BR	** see section 4.3	10-30%[12]

[5] Cramer Table 39; harvest rates for fall chinook from brood years 1979-1982. Cramer speculates that these harvest rates are not sustainable.

[6] Copying the age 4 values.

[7] From Cramer Tables 5 and 6. The values cover the range of estimated harvest rates for American River (1976-1987) and Feather River (1977-1988), thus "terminal" areas rather than the "mainstem". There was no age-specific information reported.

[8] Healey (1991), Table 8, Western U.S. (but no Sacramento information). Hankin (1990), Table 5, gave a range of 1 to 13% for June releases of Klamath River fall chinook.

[9] Hankin (1990), Table 5; Healy (1991), Table 8; Cramer, Table 38.

[10] Cramer, Table 38; Healy (1991), Table 8.

[11] From Cramer Table 14. The values cover the range of estimated stray rates for fall chinook released from hatcheries, the estuary, San Francisco Bay (based on quite small sample sizes).

[12] Wild guess.

Table 5: Input parameters for Natural Sheet

Parameter	**Column**	**Definition**	**Values**
Surrogate ID	A	Link to Hatchery Stock	ID number from hatchery sheet
Watershed	C		Menu selection
Initial Recruits	D	≡ # smolts released	Integer[1]
S-R α	E	Varies with S-R choice	Positive number[2]
S-R β	F	Varies with S-R choice	Positive number[2]

[1] Little (no?) available information on number of outmigrating natural smolts in any watershed.

[2] The meaning of these parameters depend on the choice of the S-R value on the *Globals* sheet. If **Constant** is chosen, they have no meaning and the value entered for **Initial Recruits** is used every recovery year. For linear, Ricker, and Beverton-Holt they are the formulations $\alpha + \beta S$, $\alpha S \exp[-\beta S]$, and $(\alpha S)/(\beta + S)$, respectively. See discussion in Appendix C.

4.4 Natural sheet

This sheet is linked with the Hatchery sheet by the Surrogate ID. If no parameters for the natural stock have been entered, once the Surrogate ID is entered all the survival, harvest, and maturation rates will be copied in from the corresponding Surrogate stock information on the Hatchery Sheet. Thus the user may only need to enter the few values shown in Table 4.4. However, the natural stock may be given parameters that differ from its surrogate by simply entering those into the appropriate cell. Also, make sure to enter the stray rates for each natural stock as they are not automatically entered.

5 Additional information on running CFM Sim

A tutorial (Hicks 2001) accompanies this program manual. The reader may want to now go through the tutorial which gives, step by step, the process of entering data on the *Globals*, *Hatchery*, and *Natural* sheets. The example given in the tutorial is for the case NS1, a non-selective fishery option.

Further details of the parameters input to each of the worksheets are given in Appendix C titled Running a Simulation in CFM Sim. For example, an explanation of the process of simulating rates, such as maturation rates, given the minimum, mode, and maximum values. The spawner-recruit options are explained in detail, as well. Appendix E, Additional Details of Simulation and Estimation, includes explanations of the calculations of variances of harvests and escapement used in the simulation.

6 Additional statistical information

The original statistical methodology behind NS1, NS2, S1, and S2 is available in a report by Newman (2001) and a pdf version can be downloaded from http://www.uidaho.edu/~newman/Papers/production.pdf.

The appendices to this report contain much of the information in the just mentioned document, particularly appendices A and D.

For a graphical presentation of the sequence of the survival, harvest, and maturation processes, see appendix B.

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PFMC Ad Hoc Salmon Policy Committee (?). (undated—1998?) Technical memorandum to the PSMFC on recent troll and sport hooking mortality research.

Appendix

A Background of the Constant Fractional Marking Program

Annual estimates of the abundance of hatchery reared and natural chinook salmon stocks from the Sacramento-San Joaquin river system are needed for several reasons: to detect long term trends in abundance, to set the allowable marine and freshwater harvest, and to assess the impact of habitat modifications and changes in hatchery rearing and release practices. Additional impetus for making such estimates comes from the legislative mandate, that is part of the Central Valley Project Improvement Act (CVPIA) enacted in October 1992, to double the natural chinook salmon production from each of the Sacramento-San Joaquin river system watersheds relative to a baseline period, 1967-1991. The CVPIA established a comprehensive assessment and monitoring program (CAMP) to assess progress toward attaining their goal. CAMP subsequently recommended monitoring all races of chinook salmon annually to accurately detect changes in the fish populations.

Production for a given year of a natural stock, as defined by the CVPIA, is the sum of harvest and escapement for the stock in the given year. While the focus of CVPIA is on natural stocks, it turns out that for statistical estimation purposes estimates of hatchery stock production are required and the accuracy of hatchery stock production estimates directly affects the accuracy of natural stock production estimates. Accordingly, a CAMP group and a CALFED Category III group worked jointly to develop procedures to assist in the formation of a consistent hatchery marking program, one part of which is called a constant fractional marking program or CFM, that would yield data to be used for estimation of natural and hatchery production.

The CAMP and CALFED groups had some differing objectives that led to the development of several different marking procedures. A primary objective of the CAMP group was to determine the minimum CFM rate required to provide sufficient accuracy and precision for assessing progress towards the goal of doubling natural chinook salmon production. On the other hand, an important objective of the CALFED Category III group was to develop hatchery marking options, including mass marking, that would allow assessment of the effect of selective fisheries which deliberately harvest only externally marked fish.

A total of eight marking and tagging alternatives were proposed (Newman 2000), but only four of the alternatives (#5, #6, #7, and #8) are now under consideration. Alternatives #5, #6, #7, and #8 have been renamed to NS1, NS2, S1, and S2 in this user guide. Alternatives NS1 and NS2 are suitable for a non-selective fishery, while alternatives S1 and S2 are designed with a selective fishery in place. These four alternatives have been described in Newman (2000) but are again described here for convenience.

A.1 Marking and Tagging Alternatives

The four marking and tagging schemes used in CFM Sim are described and critiqued.

A.1.1 Description of the Alternatives

- **Alternative NS1**: (Assuming no selective fishery.) There are four categories of releases within a given hatchery:

  1. experimental and *ad hoc* releases that are ad-clipped and CWT'd at any level desired, any year.
  2. a surrogate group, ad-clipped and CWT'd, assumed to represent one or more natural stocks.
  3. a fixed percentage, $c\%$, of the remainder receive both an ad-clip and distinguishing CWT,
  4. the 1-$c\%$ of the remainder receive just an ad-clip.

  Critique: This alternative allows estimation of the desired production measures, but it is more expensive than NS2 at the "front end" due to the 1-$c\%$ remainder being ad-clipped.

- **Alternative NS2**: (Assuming no selective fishery.) Like NS1 except the fourth group is left unmarked and un-tagged.

  1. experimental and *ad hoc* releases that are ad-clipped and CWT'd at any level desired, any year.
  2. a surrogate group, ad-clipped and CWT'd, assumed to represent one or more natural stocks.
  3. a fixed percentage, $c\%$, of the remainder receive both an ad-clip and distinguishing CWT,
  4. the 1-$c\%$ of the remainder are left unmarked and untagged.

  Critique: Again allows estimation of the desired production measures, but with fewer "front end" costs than NS1. On the other hand, estimation of the age class proportions of natural stocks in spawning areas is complicated by the presence of unclipped and untagged hatchery strays.

- **Alternative S1**: (Assuming a selective fishery targeting ad-clipped fish.) There are five categories of releases within a given hatchery.

  1. experimental and *ad hoc* releases that are ad-clipped and CWT'd at any level desired, any year.
  2. a stealth group, only CWT'd, assumed to represent one or more natural stocks.
  3. a surrogate for the stealth group, ad-clipped and CWT'd, assumed to represent the stealth group in terms of overwinter survival rates and maturation rates.
  4. a fixed percentage, $c\%$, of the remainder receive both an ad-clip and distinguishing CWT,
  5. the 1-$c\%$ of the remainder receive just an ad-clip.

  Critique: This alternative maximizes selective harvest opportunity. It also allows estimation of the desired production measures. However, as will be later shown, the estimation procedure is quite complicated and requires that either the maturation rates or the age 3, 4, and 5 natural survival rates be known.

- **Alternative S2**: (Assuming a selective fishery targeting ad-clipped fish.) Like S2, but the last group does not receive an ad-clip.

  1. experimental and *ad hoc* releases that are ad-clipped and CWT'd at any level desired, any year.
  2. a stealth group, only CWT'd, assumed to represent one or more natural stocks.
  3. a surrogate for the stealth group, ad-clipped and CWT'd, assumed to represent the stealth group in terms of overwinter survival rates and maturation rates.
  4. a fixed percentage, $c\%$, of the remainder receive both an ad-clip and distinguishing CWT,
  5. the 1-$c\%$ of the remainder are left unmarked and untagged.

  Critique: As for S2, estimation of the desired production measures can be done, but is complicated and requires knowing maturation or natural survival rates. It perhaps reduces data generation costs, but does not maximize selective harvest opportunity. Like NS2, estimation of the age class proportions of natural stocks in spawning areas is complicated by the presence of unclipped and untagged hatchery strays.

A.2 Purpose of CFM Sim

The main purpose of CFM Sim is to provide a means for managers to evaluate the effects of changes in marking and sampling rates on the quality of estimates of production for alternatives NS1, NS2, S1, and S2. Furthermore, direct comparisons between alternatives NS1 and NS2 and between alternatives S1 and S2 can be made using CFM Sim. There is also the ability to simulate a sequence of recovery years, which can help determine if long term estimation goals can be met with set marking and sampling rates used in a specific alternative.

Each of the four alternatives explained above contain enough information to estimate the production of each stock, but the amount of marking, sampling, and tagging to produce the best estimates of production is unknown. CFM Sim can help determine the marking and sampling rates and/or number of tagged releases in a specific marking alternative that would produce the best estimates of production, given user defined parameters such as survival and harvest rates. The user can simply enter in the "true" parameters for a number of stocks and CFM Sim will simulate the sequence of events of each stock. This sequence consists of initial survival, ocean harvest, overwinter survival, maturation, and freshwater harvest. Sampling is performed within each simulated recovery year and production estimates of each stock are recorded and compared to the "true" production simulated by CFM Sim for that recovery year. This process is repeated a specified number of times to determine the variability that can occur.

B Notation, Sequence, and Assumptions

The model used by CFM Sim is a cohort model similar to that described in Hankin and Healey (1986). It assumes that each fate of a fish follows in a sequential manner.

B.1 Notation

The notation follows somewhat from Hankin and Healey (1986) and Newman (2000). The term stock is used to designate a particular hatchery release group, or fish that are the progeny of naturally spawning returns to a particular watershed. In this section the suffix x denotes a particular stock, but in later sections n and h will be used to distinguish natural and hatchery stocks. Table 6 explains the notation used in the explanation of the alternatives.

Table 6: The notation used in the explanation of the CFM alternatives.

$\mathbf{R_x}$	number of juvenile fish released from hatchery x or naturally produced juvenile fish (recruits) from watershed x
$\mathbf{N_{x,a}}$	abundance of age a fish from stock x immediately prior to ocean harvest. Noted as *In Ocean at age a* in Figure 1
$\mathbf{S_{x,I}}$	probability of surviving from time of release to beginning of ocean harvest, where I stands for initial
$\mathbf{S_{x,a}}$	probability an unharvested, immature, age $a-1$ fish from stock x is alive at age a prior to fishing, $a = 3, 4, 5$
$\mu_{\mathbf{O,x,a}}$	ocean fishery harvest rate on age a fish
$\mu_{\mathbf{F,x,a}}$	freshwater mainstem (pre-watershed) fishery harvest rate on age a fish
$\mu_{\mathbf{T,x,a}}$	freshwater terminal (watershed) fishery harvest rate on age a fish
$\mathbf{C_{O,x,a}}$	number of age a fish from stock x harvested in the ocean
$\mathbf{C_{F,x,a}}$	number of age a fish from stock x harvested in the freshwater mainstem, *prior* to reaching a spawning area
$\mathbf{C_{T,x,a,j}}$	number of age a fish from stock x harvested in the terminal fishery of watershed j
$\sigma_{\mathbf{x,a}}$	probability an age a fish from stock x matures at age a, given survival to age a without maturing earlier
$\mathbf{E_{q,x,a}}$	total in-hatchery freshwater escapement of age a fish from stock x. Natural stocks include strays, while hatchery stocks do not
$\mathbf{E_{r,x,a}}$	total in-river freshwater escapement of age a fish from stock x. Natural stocks include strays, while hatchery stocks do not
η	the probability that a fish will be taken by the hatchery to spawn. The complement of this, $1-\eta$, is the probability that a fish will spawn naturally in the watershed and contribute to next year's natural stock

Catch and escapement summed over stocks and/or ages are denoted by dropping subscripts; e.g., C_O is total ocean catch of all ages and stocks for a given year.

B.2 Sequence of Processes

The following oversimplification of chinook salmon life history will be assumed. Juvenile chinook salmon leave freshwater and enter the ocean sometime during their first year (age 1). Next follows a sequence of binary events "experienced" by fish still alive at each point in time: overwinter survival or not, harvest or not by the ocean fishery, maturation or not. If maturing: harvest or not by a freshwater mainstem fishery, then harvest or not by a terminal area fishery. The fish that survive through the terminal fishery are counted as escapement in the watershed, therefore all terminal fisheries are assumed to occur before a fish escapes to spawn. The escapement may then be split into fish escaping in the river and those that enter the hatchery, if one is present. Maturing fish in the freshwater system are assumed to have 100% survival, outside of the fisheries. In other words, the fish in the freshwater system do not die of natural causes. If maturation is less than 100%, those fish not maturing repeat the above cycle of overwinter survival, ocean harvest, and maturation. Figures 1 and 2 graphically show the sequence of events in the salmon's life history.

However, fish can stray between watersheds, thus the fish that survive through the freshwater mainstem fishery are partitioned among the watersheds according to their straying probabilities. The separate groups in each watershed then experience the watershed specific terminal fishery, with the survivors escaping to that watershed.

For watersheds that contain a hatchery, all terminal fishing is assumed to occur downstream of the hatchery before the fish spawn. The escaping fish are then split into those that are taken by the hatchery (in-hatchery escapement), and those that spawn naturally in the watershed (in-river escapement) and contribute to next year's natural recruitment.

The probability of each fate is conditional on the fish surviving up to the point where it would experience the fate. For example, denote the probability that a fish is caught in the ocean fishery at age 3, given it has survived up to age 3, as $\mu_{O,3}$. This probability is conditional on the fish surviving up to the time it would experience the ocean fishery. However, the probability that the fish would be caught in the ocean fishery at age 3 after release is the product of the probabilities of all previous conditional fates and $\mu_{O,3}$.

$$P(\text{Caught in Ocean Fishery at Age 3}) = S_I(1-\mu_{O,2})(1-\sigma_2)S_3\mu_{O,3} \qquad (1)$$

where S signifies survival (initial and overwinter), $\mu_{O,a}$ is the probability of being harvested in the ocean fishery at age a, and σ_2 is the probability of maturing at age 2. Using the notation described in Table 6, the probabilities and expected values of all the fates in Figures 1 and 2 can be defined.

Given this assumed sequence of events, the expected abundance in the ocean of age a fish from stock x, is a function of previous survival, harvest, and maturation rates. For example, assuming harvest begins at age 2

$$\text{E}[N_{x,4}] = R_x S_{x,I}(1-\mu_{O,x,2})(1-\sigma_{x,2})S_{x,3}(1-\mu_{O,x,3})(1-\sigma_{x,3})S_{x,4}.$$

Conditional on the abundance in the ocean at age a, $N_{x,a}$, the expected catches and escapements for age a fish are

$$\begin{aligned}
\text{E}[C_{O,x,a}|N_{x,a}] &= N_{x,a}\mu_{O,x,a} \\
\text{E}[C_{F,x,a}|N_{x,a}] &= N_{x,a}(1-\mu_{O,x,a})\sigma_{x,a}\mu_{F,x,a} \\
\text{E}[C_{T,x,a}|N_{x,a}] &= N_{x,a}(1-\mu_{O,x,a})\sigma_{x,a}(1-\mu_{F,x,a})\mu_{T,x,a} \\
\text{E}[E_{x,a}|N_{x,a}] &= N_{x,a}(1-\mu_{x,a})\sigma_{x,a}(1-\mu_{F,x,a})(1-\mu_{T,x,a})
\end{aligned}$$

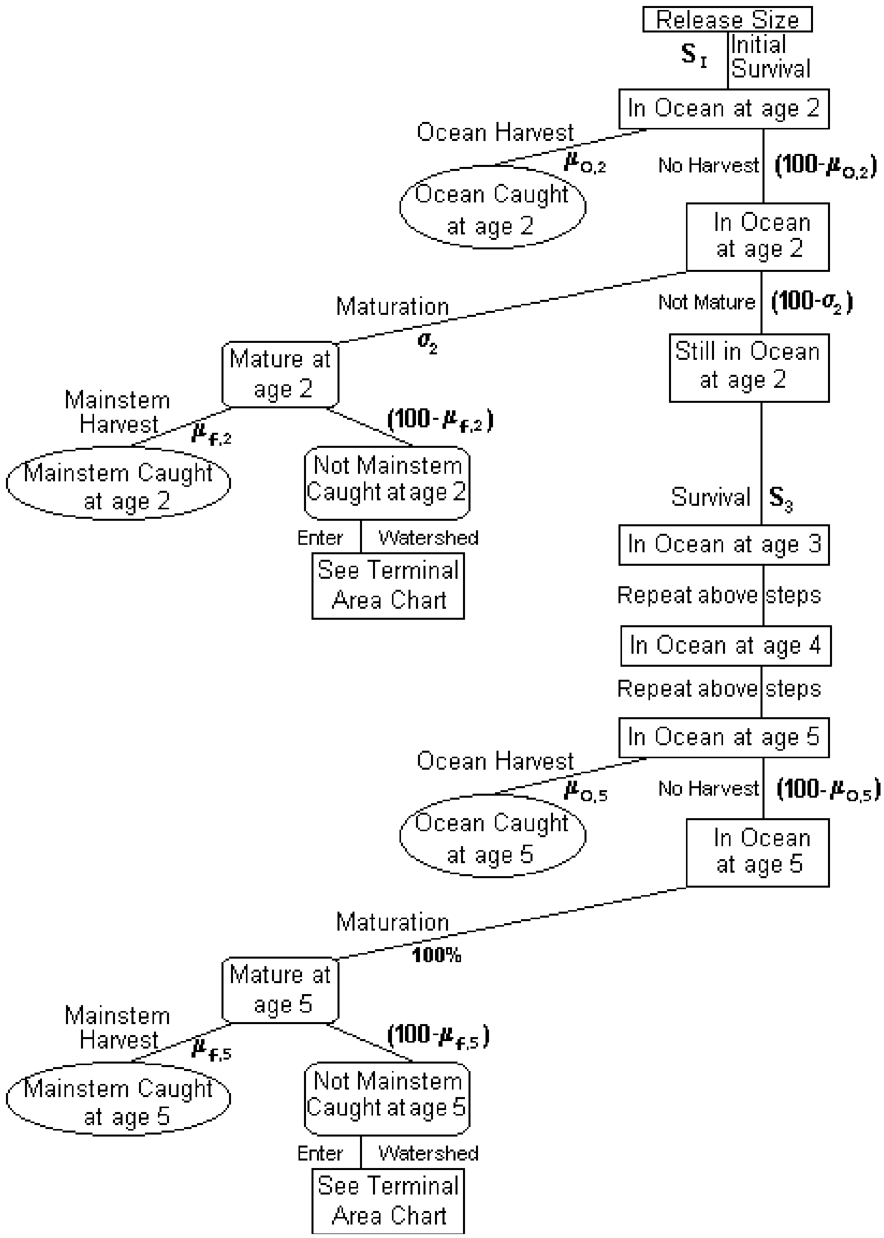

Figure 1: The sequence of fates that a fish can have. The bold faced type denotes the probabilities associated with that fate.

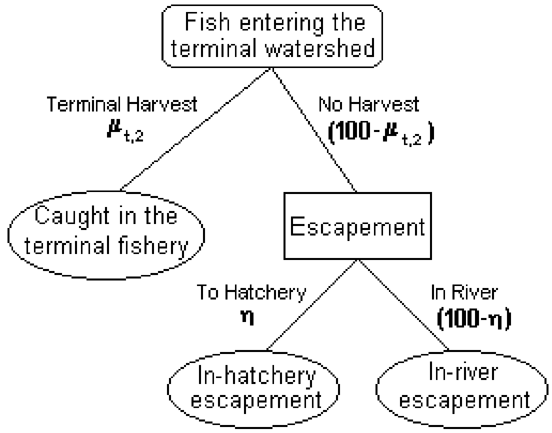

Figure 2: The sequence of fates that a fish can face in the terminal watershed. The bold faced type denotes the probabilities associated with that fate.

The production for a given stock, natural or hatchery, is the harvest and escapement summed over ages. CFM Sim assumes ages 2, 3, 4, and 5 are harvested, maturation begins at age 2 (and such "jacks" are counted in production) and all uncaught age 5 fish mature. Therefore, the production is

$$P_x = \sum_{a=2}^{5} \left[C_{O,x,a} + C_{F,x,a} + C_{T,x,a} + E_{x,a} \right].$$

B.3 Assumptions

Because natural fish are assumed unmarked and untagged, for each natural stock there must be an identifiable hatchery stock to serve as a surrogate. Per cohort, the surrogate hatchery stock and the natural stock are assumed to have the same overwinter survival rates, exploitation rates, and maturation probabilities. Surrogates are needed whether or not a selective fishery takes place, but the marking strategies must differ. In the presence of a selective fishery some hatchery fish will need to be left unmarked (externally) while containing some non-obvious identifier, namely a coded wire tag (CWT). Groups of fish with intact adipose fins and CWTs will be referred to as *stealth groups*.

The assumption that a hatchery stock is a surrogate to a natural stock is critical to the accuracy and precision of the production estimates. Studies should be performed to determine if the natural stock has similar survival, harvest, and maturation rates as the hatchery stock acting as its surrogate.

Simple random samples (SRS) are assumed for the sampling of harvest and escapement. Thus, all temporal and spatial stratification is ignored. In the case of harvest, SRS's of sizes n_O n_F, and n_{T_j} are taken from the total ocean and freshwater harvests (C_O, C_F, and C_{T_j}) where j refers to the watershed. Likewise for in-river and in-hatchery escapement, SRS's of size $n_{E_{q,j}}$ and $n_{E_{r,j}}$ are taken from the in-river and in-hatchery escapements to watershed j, denoted $E_{q,j}$ and $E_{r,j}$, respectively.

This oversimplification is disadvantageous in that the precision of catch data may be underestimated compared to the stratified samples actually taken from ocean fisheries. For escapement estimation, it is difficult to say what the actual precision is, or will be, but some degree of stratification would likely be done.

A further assumption, also not realistic, is that snouts are removed from every tagged recovery. This is not controversial for harvest samples, but could be so for escapement samples of live fish. Relatedly when stealth groups are present, every unmarked fish is assumed scanned for the presence of a CWT and the snout removed when a CWT is detected. The estimation procedures can be modified, however, if subsampling of tagged recoveries is done.

C Running a Simulation in CFM Sim

CFM Sim uses a familiar spreadsheet format, called Formula One, developed by Visual Components, Inc. Little training is needed to learn how to run a simulation if one is already familiar with other popular spreadsheet programs. However, a fair amount of knowledge of chinook salmon life history is required.

C.1 General Program Operation

The program opens with a blank workbook containing three sheets for data entry: 1)*Global*, 2)*Hatchery*, and 3)*Natural*. The sheets must appear in this order for the program to run correctly. The *Globals* sheet contains parameters that are constant for all stocks, such as the constant fractional marking (CFM) rate. The *Hatchery* and *Natural* sheets contain the parameters for hatchery and natural stocks, respectively. A sheet can be viewed by simply clicking on the tabs at the bottom of the program window.

The top of the program window has a menu bar and a tool bar containing rudimentary operations such as saving and opening files, as well as the commands to begin a simulation of one of the marking alternatives. If the cursor is left momentarily on a toolbar button, a hint will appear explaining the function of the button.

C.1.1 File Menu

The *File* menu contains commands to open, save, or create new files. It also has an exit command that will quit the program. The *New* command will create a new workbook with the three sheets listed above. There will be no data entered. The *Open* command will open a previously saved Formula One workbook. The workbook must have been saved with the extension *.vts*. The *Save* option will save the current workbook. If the workbook has already been named, it will save it without any prompts. However, if the workbook has not been previously saved (does not have a *.vts* extension) it will bring up the Save As dialog box and prompt the user to name the workbook. The *Save As...* command will bring up the Save As dialog box and allow the user to name the current workbook before saving it. Finally, the *Exit* command will quit the program, prompting to save if the workbook has been modified since the last save. Table 7 summarizes each command available in the *File* menu.

Table 7: Commands within the *File* menu.

Command	**Description**
New	Creates a new blank workbook with three worksheets.
Open	Opens a previously saved Formula One workbook.
Save	Saves the current workbook without prompting to rename.
Save As...	Allows the current workbook to be renamed before saving it.
Exit	Quits CFM Sim.

C.1.2 Edit Menu

Table 8 summarizes the commands found in the **Edit** menu. The *Cut*, *Copy*, and *Paste* commands work in the familiar way, except that they will only cut, copy, or paste the values in the cells and not any of the formats. *Delete Row* will delete the entire row or rows which have at least one cell selected, and shift the lower row up. This command is for deleting stocks from the *Hatchery* or *Natural* sheet and will not work on the *Globals* sheet.

Aging Errors Matrix The simulation can incorporate errors that occur when aging the fish. For example, errors occur when a fish of age 3 is classified as age 2, and so on. Therefore, the vector of true simulated ages is multiplied by a matrix of conditional probabilities for classifying a fish as an age given its true age. The equation looks like this,

$$\begin{bmatrix} True2 & True3 & True4 & True5 \end{bmatrix} \times \mathbf{A} \tag{2}$$

where **A** is a matrix containing the conditional probabilities.

$$\mathbf{A} = \begin{matrix} \text{T} & \text{A} \\ \text{r} & \text{g} \\ \text{u} & \text{e} \\ \text{e} & \end{matrix} \overset{\text{Assigned Age}}{\begin{bmatrix} P(2|2) & P(3|2) & P(4|2) & P(5|2) \\ P(2|3) & P(3|3) & P(4|3) & P(5|3) \\ P(2|4) & P(3|4) & P(4|4) & P(5|4) \\ P(2|5) & P(3|5) & P(4|5) & P(5|5) \end{bmatrix}} \tag{3}$$

The matrix **A** in equation (3) is filled in, by the user, with values which denote the percentage of time a fish is classified as an age, given its true age. For example, if age 3 fish are classified as age 4, 3% of the time, the value "3" should be entered in the second row and third column of the aging error matrix. The matrix should be filled with probabilities such that each row sums to 100. The *Defaults* button can be pressed to restore the pre-defined defaults that are believed to be representative of current aging errors. If every fish is classified as its true age, pressing the *No Error* button will enter a diagonal matrix with 100's on the diagonal to accomplish this. There is also a parameter on the *Globals* sheet called **Aging Sampling Rate** which will contribute sampling error to the age estimates. See Sections C.2.2 and E.3.1 for a more thorough discussion on how to completely eliminate sampling and classification aging errors from the simulation.

Spawner Weighting If multiple recovery years are being simulated, the natural stocks use a spawner-recruitment curve to determine the number of next year's recruits (see Sections C.2.2 and E.2). To determine the number of spawners in the spawner-recruitment curve, certain age groups of the female spawners should be weighted differently, according to their contribution to the number of next year's recruits. The Spawner Weighting form allows the entry of *the percent contribution of a female spawner in a specified age class to next year's recruits, relative to an age 5 female.* This means, if an age 4 female contributes 80% the number of recruits that an age 5 female would contribute, enter "80" for age 4 females. A percentage larger than 100 may be entered, suggesting an age class has a larger contribution than the age 5 females. Also, if an age class does not contribute to next year's recruits, say, if age 2 fish are comprised completely of males, enter a zero for that age. See Section E.2 for more detailed information on how the number of spawners is calculated. The *Default* button will enter zero for age 2 fish (assumes only jacks return) and 100 for both age 3 and age 4 fish (assuming age 3, 4, and 5 fish contribute equally to the number of next year's recruits).

Table 8: Commands within the *Edit* menu.

Command	Description
Delete Row	Deletes the current row on the *Hatchery* or *Natural* sheet. Non-functional on the *Globals* sheet.
Cut	Cuts the value or values from the currently selected cell or cells and copies them to the clipboard for later pasting.
Copy	Copies the value or values from the currently selected cell or cells to the clipboard for later pasting.
Paste	Pastes the clipboard into the currently selected cell or cells.
Aging Errors	Displays a form to change the aging error matrix defined by equation (3).
Spawner Weighting	Displays a form to change the age specific spawner weights.

C.1.3 Run Menu

The *Run* menu contains the commands to begin the simulation using alternatives NS1, NS2, S1, or S2. Simply select the alternative from the *Run* menu, or click the appropriate toolbar button. Also, the F5, F6, F7, or F8 key will begin a simulation using alternative NS1, NS2, S1, or S2, respectively.

C.1.4 About Menu

Selecting *About...* in the *About* menu displays information about CFM Sim.

C.2 Data Entry

The data necessary to run a simulation is entered on the three sheets, *Globals*, *Hatchery*, and *Natural*. This section explains every parameter to be entered on these three sheets, as did the main section of this program manual.

C.2.1 Entering Parameters

Entering a parameter is straightforward. Simply type the number into the cell and press Enter, one of the arrow keys, or click on another cell. Most parameters are a rate and ***must be entered as a percentage***. Examples of rates are harvest rates, the constant fractional marking rate, and maturity rates. Other parameters include the number of simulations, release sizes, and watershed names.

There are 14 defined watersheds in CFM Sim, where terminal fisheries and spawning occurs. They are: American River, Battle Creek, Butte Creek, Clear Creek, Deer Creek, Feather River, Merced River, Mill Creek, Mokelumne River, Sacramento River, San Joaquin River, Tuolumne River, and Yuba River.Some parameters apply only to terminal areas thus are watershed specific. To not include a watershed in an analysis, simply set all of its values to zero or leave it blank.

Each survival, maturity, and harvest rate parameter has a minimum value, maximum value, and mode value to be entered in percentages. These values define a triangle distribution from which the parameter will be drawn. This allows the parameters to vary between years and over simulations, mimicking the normal fluctuations present in these parameters. The amount of randomness is determined by setting the minimum, mode, and maximum of the parameter. The minimum and maximum are the smallest and largest values that the parameter can take on, respectively. The mode is the value that occurs most often and is also the peak in the triangle distribution. Figure 3 shows what a triangle distribution looks like and where the minimum, maximum, and mode values occur. The distribution does not have to be symmetric and the mode can equal the minimum or

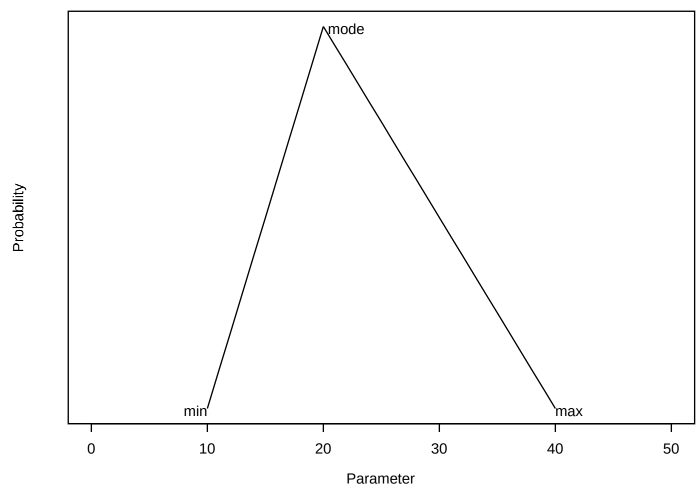

Figure 3: A triangle distribution showing the three parameters to input. The minimum is 10, the maximum is 40, and the mode is 20.

the maximum. If fact, when the minimum, mode, and maximum are all equal, the parameter is constant and does not fluctuate. However, the minimum must not be greater than the maximum or mode, and the maximum must not be less than the minimum or mode. Minimum and maximum are abbreviated *min* and *max* in the headings of the parameters.

C.2.2 Parameters on the Globals Sheet

The *Globals* sheet contains parameters that are not stock specific, such as sampling rates, watershed specific parameters, the number of simulations, the number of years, and a random seed parameter. Table 9 explains the various parameters and some of the parameters are discussed in detail below.

The **CFM rate** is the percentage of fish, not in the Ad Hoc, Surrogate, or Stealth release groups, that must be tagged and clipped. This parameter is constant over all hatchery stocks.

When the number of years being simulated exceeds one, the next year's watershed specific natural recruitment is calculated using the spawner-recruitment curve specified. An initial recruitment is entered for each natural stock to begin the simulation. The number of recruits is then determined using the number of spawning females in the watershed and the chosen spawner-recruitment curve. There are four options for the spawner-recruitment curve.

Table 9: *Globals* sheet parameters.

Parameter	**Description**
CFM Rate	The percentage of fish, not including Ad Hoc, Surrogate, and Stealth releases, to be coded-wire tagged and fin clipped.
Sampling Rate of Total Ocean Harvest	The percentage of the total ocean harvest for one entire season, including commercial and recreational fisheries, that is sampled for tags and/or marks.
Sampling Rate of Ocean Sport Catch	The percentage of only the total ocean recreational catch, for one entire season, that is sampled for tags and/or marks.
% of Total Ocean Catch from Sport Fishery	The percentage of the total commercial and recreational ocean catch for one entire season that is caught in the recreational fishery.
S-R Model	The spawner-recruitment model used to calculate next year's natural recruits. Choose from Constant, Linear, Ricker, or Beverton-Holt.
S-R Percent CV	The coefficient of variation associated with the spawner-recruitment calculation. Adds variability to the recruitment. Entered as a percentage.
Mainstem Harvest Sampling Rate	The percentage of the total freshwater mainstem harvest for one entire season that is sampled for tags and/or marks. The freshwater mainstem is the area of the rivers that a fish passes through before entering any defined watershed where a terminal fishery occurs or fish spawn.
In-River Escapement Sampling Rate	The percentage of the watershed's total in-river escapement that is sampled for tags/marks over one entire season. Entered as a percentage.
In-Hatchery Escapement Sampling Rate	The percentage of the total in-hatchery escapement of the current watershed that is sampled for tags/marks in one season. Watersheds with no hatchery are ignored. Entered as a percentage.
Terminal Harvest Sampling Rate	The percentage of the total terminal harvest in that watershed that is sampled for tags/marks in one season. Entered as a percentage.
Age n Terminal Harvest Rate (Min)	The minimum value of the terminal harvest rate on age n fish in the specific watershed. Entered as a percentage.
Age n Terminal Harvest Rate (Mode)	The mode of the triangle distribution for terminal harvest rate on age n fish in the specific watershed. Entered as a percentage.
Age n Terminal Harvest Rate (Max)	The maximum value of the terminal harvest rate on age n fish in the specific watershed. Entered as a percentage.
Ocean Shaker Mortality Rate	Age specific % of unmarked fish that suffer incidental mortality due to being caught and released in the selective ocean fishery. Alternatives S1 and S2 only. Entered as a percentage.
Freshwater Shaker Mortality Rate	Age specific % of unmarked fish that suffer incidental mortality due to being caught and released in the selective freshwater mainstem fishery. Alternatives S1 and S2 only. Entered as a percentage.
Terminal Shaker Mortality Rate	Age specific % of unmarked fish that suffer incidental mortality due to being caught and released in the selective freshwater terminal fishery of any watershed. Alternatives S1 and S2 only. Entered as a percentage.
Aging Sampling Rate	The percentage of fish sampled from each watershed's in-river escapement sample to be aged. Explained more in Section E.3.1.
Number of Simulations	The number of outer simulations to run. One outer simulation runs through all recovery years. Maximum of 10000.
Number of Years	The number of recovery years to simulate and estimate. This occurs within one outer simulation. Maximum of 100.
Seed (Enter 1 for a random seed)	Allows random simulations to be repeated. Enter a 1 for a random seed value, or any other integer from 2 to 32000 for reproducible results.

1. **Constant** Each year's recruitment is the initial recruitment entered on the *Natural* sheet.

2. **Linear** The next year's recruitment is determined from a linear relationship between spawners and recruits. The relationship has a user defined intercept α and slope β.

$$R = \alpha + \beta S$$

3. **Ricker** The number of recruits increases with low spawner levels, but then begins to decrease when numbers of spawners gets large. The parameter α is an intrinsic rate of growth parameter and β can be thought of as a density dependence parameter.

$$R = \alpha S e^{-\beta S}$$

4. **Beverton-Holt** The number of recruits increases and approaches a maximum number. The parameter α is a intrinsic rate of growth parameter and β can be thought of as a density dependence parameter.

$$R = \frac{\alpha S}{\beta + S}$$

The shapes of these four spawner-recruitment curves are shown in Figure 4.

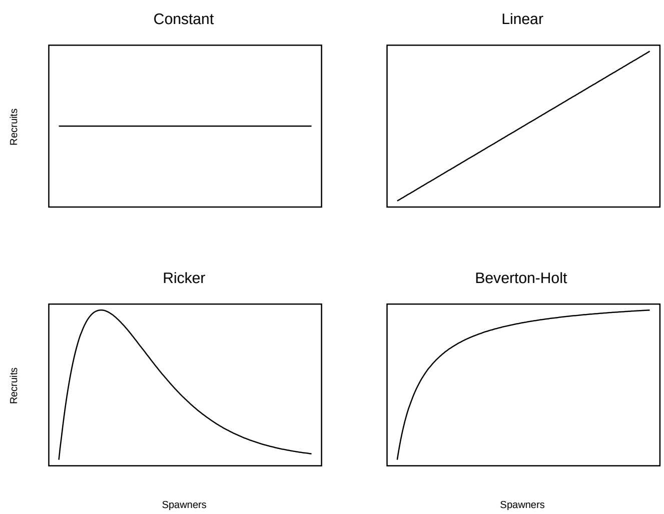

Figure 4: Shapes of the four spawner-recruitment curves that can be used.

For watersheds that contain a hatchery, the escapement is split into fish that escape in the river (in-river escapement) and fish that escape to the hatchery (in-hatchery escapement). Both of these groups can contain hatchery and natural fish, if desired, by entering parameters on the *Hatchery* sheet for fish that escape to the hatchery . The sampling rates may be different for in-river escapement and in-hatchery escapement.

The **Terminal Harvest Rates** are age and watershed specific, and may come from a random triangle distribution. Therefore, the three parameters, minimum, mode, and maximum, must be entered as explained in Section C.2.1 and shown in Figure 3. The age specific harvest is the percentage of age n fish caught in the terminal watershed out of all available age n fish in that watershed's terminal fishery, over the course of the season. Possible methods to find plausible values for these rates are explained in Section C.2.3. If there is no terminal fishery in the watershed, enter zeros for the minimum, mode, and maximum of all age groups in the watershed.

The **Incidental Mortality Rates** are age-specific, but the same for all stocks. There are separate rates for the ocean, freshwater mainstem, and terminal fisheries. They are the percentage of unmarked fish of the specific age group that suffer incidental mortality after being caught and released in the selective fishery, out of all of the unmarked fish of the age group that are caught and released in the selective fishery. In other words, the shaker mortality rate is the probability that an unmarked fish will die after being caught and released, expressed as a percentage. For example, if 10% of the age three fish in the ocean fishery suffer incidental mortality, and 1000, age three, unmarked fish were caught, approximately 100 would die after being released. This would leave 900 of these fish to move to the next sequence in life history events. All of the fisheries are assumed to be selective for unmarked fish in alternatives S1 and S2. Therefore, if the shaker mortality rate is set to zero, that implies all unmarked fish survive after being released from the fishery. The unmarked fish are *not* included in the catch.

The **Aging Sampling Rate** is the percentage of fish sampled from each watershed specific in-river escapement sample to be aged. The watershed specific in-river escapement sample is all of the fish that were examined for hatchery tags in the watershed's in-river escapement. Therefore, the aging sample is a subset of the sample examined for tags. More is explained in Section E.3.1.

A single simulation runs through the number of recovery years defined by the parameter **Number of Years**. The **Number of Simulations** is then the number of times the years are cycled through. Multiple years can give ideas as to how the stocks are changing over time and what production may be like in years to come. The multiple simulations give an impression of the possible sampling distribution of the error in production.

CFM Sim uses random number generators to allocate fish to each of the possible fates. Setting the random seed to a number other than 1 will allow the results to be exactly reproduced. Setting the **Seed** parameter to 1 results in the computer randomly setting the random seed, resulting in a truly random simulation. Of course, the user may pick an integer at random to randomly set the seed, yet allow the results to be reproduced.

C.2.3 Hatchery and Natural Sheets

The *Hatchery* and *Natural* sheets contain the stock specific parameters. There is one stock per row with all of its parameters in the columns. Stocks must be entered from row one downward, and it is very important that there are no blank rows between any of the stocks, as some stocks may not be included in the simulation. The following sections describe the parameters.

C.2.4 Hatchery stock identifiers and release sizes

The first few columns contain general stock parameters and release sizes. Table 10 explains these variables. The *Hatchery* sheet has a column for the **Stock Name**, which ***must*** be entered for that stock and any below it to be considered in the simulation. When a cell in the watershed column is selected, a list box appears with choices of the fourteen possible watersheds. Simply choose the watershed that the stock is native to. Only one hatchery can be located on each of these watersheds and must be located only on these pre-defined watersheds There does not need to be a hatchery on every watershed.

Table 10: Stock ID and release parameters on the *Hatchery* sheet.

Parameter	**Description**
Stock Name	A name for the stock. Must contain a name to be considered in the simulation.
Watershed	The watershed that the stock is native to. Choose from a list.
Total Release	The total release size of the stock for every year.
Ad Hoc Release	The number of tagged experimental and *ad hoc* releases of the stock.
Surrogate Release	The number of tagged surrogate fish released of the stock.
CFM Release	The number of CFM releases. This number is calculated using the CFM rate from the *Globals* page. **Not entered by the user**.
Remaining Release	The number of remaining fish released. It is calculated by the program. **Not entered by the user**.
Stealth Release	The number of fish released in the stealth group of the stock. For use only in alternatives S1 and S2.

The **Total Release** is the total number of fish, tagged or not, in the stock that were released from the hatchery. There are also entries for the number of fish released in each respective tag group: *ad hoc*, surrogate, CFM, remaining, and stealth. The sum of all of these tag groups will total the **Total Release** number. However, **CFM Release** and **Remaining Release** should not be entered as the program will calculate them using the total releases, the number in the other tagged releases, and the CFM rate. After a simulation is run, the correct numbers will appear in these columns. **Ad Hoc Release** and **Surrogate Release** numbers must be entered, although ad hoc releases may be zero. **Stealth Release** numbers must be entered for alternatives S1 and S2, but any number in that column will be ignored for alternatives NS1 and NS2.

C.2.5 Natural stock identifiers and release sizes

The first few columns of the *Natural* sheet also contain general stock parameters and release sizes. Table 11 explains these variables. A native watershed is chosen the same way as on the *Hatchery* sheet. There is no **Stock Name** for the natural stocks because they use the name of the watershed to identify them. Therefore, a watershed ***must*** be entered in the watershed column of the *Natural* sheet for that stock, and any below it, to be considered in the simulation. There does not need to be a natural stock on each watershed.

The *Natural* sheet has a few columns that the *Hatchery* sheet does not. One of them is for the surrogate **ID**. This is an integer value that corresponds to the row number of the hatchery stock that is to be used as the natural stock's surrogate. The idea of a surrogate is explained in Section A.1. When an **ID** is entered in this column, and no data has been entered for that natural stock, the hatchery surrogate's parameters are automatically entered. However, it may not be correct to assume that the surrogate and natural stock have the same parameters, and it may be worthwhile

Table 11: Stock identifier and recruitment parameters on the Natural sheet.

Parameter	Description
ID	The row number from the *Hatchery* sheet of the hatchery stock that acts as a surrogate to the Natural stock.
Check to Create an Output File	Check this box to create an output file that writes recruitment sizes, true production, and estimated production of the stock.
Watershed	The watershed that the stock is native to. Choose from a list.
Initial Recruits	The number of newly emerged fry resulting from last year's spawning females. If the spawner-recruitment curve is Constant, this is the recruitment for all recovery years.
S-R alpha Param	The α parameter in the spawner-recruitment function.
S-R beta Param	The β parameter in the spawner-recruitment function.

to study the effects of using surrogate stocks with different parameters than the natural stock. The other column unique to the *Natural* sheet is the **Check to Create an Output File** column. This column contains check boxes which determine if that stock's simulated recruitment, catches, escapement, true production, and estimated production will be written to a file. However, these files may become big when running a large number of simulations. More is explained in Section C.4.

The **Initial Recruits** are the total number of recruits for the first simulated year. Again, a recruit is a newly emerged fish resulting from last year's naturally spawning females. This fish will next experience initial survival in its sequence of life history events. Chapter B explains the sequence of events more clearly.

When the number of years being simulated exceeds 1, the natural stock's recruitment is calculated using the spawner-recruitment function specified on the *Globals* page. The α and β parameters for the Linear, Ricker, and Beverton-Holt spawner-recruitment functions are set on the *Natural* sheet under the columns labeled **S-R alpha Param** and **S-R beta Param**. Both parameters must be greater than zero. These parameters are ignored if the Constant spawner-recruitment function is chosen.

WARNING

If simulating more than one recovery year, it is very important to choose realistic α and β parameters for the spawner-recruitment curves. The choice of these parameters can drive a stock to extinction or make it grow at an unrealistic rate, and will greatly affect the results of the simulation. It is a good idea to draw spawner-recruitment curves, using another program, that will show the possible scenarios under various spawner sizes. Also Section C.4 explains the output files and how these can be used to determine the effect the α and β parameters are having on the natural stocks.

C.2.6 Survival, Harvest, and Maturation Parameters

The bulk of the data entry involves entering parameters for survival, harvest, and maturation. Parameters are entered for each age from 2 through 5. Age 5 fish mature with a probability of 1, thus the **Maturity Rate Age 5** parameter is already entered at 100, and cannot be changed.

The simulation draws the yearly parameters from a triangle distribution as described before (Section C.2.1 and Figure 3). Therefore, the user must enter a minimum, mode, and maximum value for each parameter. Again, if the parameter is not random, enter the same values for minimum, mode, and maximum.

Tables 12 explains the meaning of the parameters to be entered. The *Hatchery* and *Natural* sheets have a minimum, mode, and maximum of the triangle distribution for each survival, harvest, and maturity parameter, which are noted with **Min**, **Mode**, and **Max**.

The initial survival (**Survival Initial**) of a fish is the percentage of recruits, from the specific stock, that survive to age 2 to next experience the ocean fishery. The age 3, 4, and 5 **Survival** parameters are the overwinter survival rates, for that specific age, if a fish does not mature the previous year. Past catch data and equations (24)–(27) in Section D.3 can be used to estimate a range of values to input as the initial survival of a specific stock.

Table 12: Survival, harvest, and maturation parameters on the *Hatchery* and *Natural* sheets. n refers to the age which that parameter is associated with. For example, **Ocean Harvest Age** n, can represent **Ocean Harvest Age 2**, **Ocean Harvest Age 3**, **Ocean Harvest Age 4**, or **Ocean Harvest Age 5**.

Parameter	Description
Survival Initial	The percentage of recruits that survive to age 2 in the ocean. This is commonly called initial survival.
Survival Age n	The percentage of age $n-1$ fish that survive to age n, of the specific stock. This is experienced after age $n-1$ maturity and before age n ocean harvest. n is 3, 4, or 5. Commonly known as overwinter survival.
Ocean Harvest Age n	The percentage of age n fish of the specific stock, out of all age n fish of the stock that are in the ocean over one season, that are harvested in the ocean fishery (commercial and recreational). The fish experience the ocean fishery after overwinter survival and before possibly maturing.
Mainstem Harvest Age n	The percentage of age n fish of the specific stock, out of all age n fish of the stock that are in the freshwater mainstem over one season, that are harvested in the freshwater mainstem fishery. The fish experience the freshwater mainstem fishery after maturing and before entering the terminal area.
Maturity Rate Age n	The probability (in percent) that an age n fish of the stock matures and enters the freshwater system to begin migrating to its spawning grounds. Experienced immediately after the ocean fishery. Age 5 is set at 100.

A **Harvest** parameter is the percentage of the age n fish, from the given stock, that are harvested in the fishery. This percentage is with respect to all fish from the given stock that are alive at age

n over the course of one fishing season. For example, if there are 1000 fish from stock "A" available to the ocean fishery and the ocean harvest rate on stock "A" is 20%, then there would be an expected ocean catch of 200 fish. The rates can be assigned a triangle distribution, which allows an acceptable range to be applied to the parameter.

Estimates of ocean harvest rates for stock x can be found using CWT recovery data to give an idea of the range of the true harvest rates to input into CFM Sim, when simulating an actual system.

$$\widehat{\mu}_{O,2,t-2} = \frac{\widehat{C}_{O,2,t-2}}{R_{t-2}\widehat{S}_{I,t-2}} \tag{4}$$

$$\widehat{\mu}_{O,3,t-3} = \frac{\widehat{C}_{O,3,t-3}}{R_{t-3}\widehat{S}_{I,t-3}(1-\widehat{\mu}_{O,2,t-3})(1-\hat{\sigma}_{2,t-3})S_3} \tag{5}$$

$$\widehat{\mu}_{O,4,t-4} = \frac{\widehat{C}_{O,4,t-4}}{R_{t-4}\widehat{S}_{I,t-4}(1-\widehat{\mu}_{O,2,t-4})(1-\hat{\sigma}_{2,t-4})S_3(1-\widehat{\mu}_{O,3,t-4})(1-\hat{\sigma}_{3,t-4})S_4} \tag{6}$$

$$\widehat{\mu}_{O,5,t-5} = \frac{\widehat{C}_{O,5,t-5}}{R_{t-5}\widehat{S}_{I,t-5}(1-\widehat{\mu}_{O,2,t-5})(1-\hat{\sigma}_{2,t-5})S_3(1-\widehat{\mu}_{O,3,t-5})(1-\hat{\sigma}_{3,t-5})S_4(1-\widehat{\mu}_{O,4,t-5})(1-\hat{\sigma}_{5,t-5})S_5} \tag{7}$$

The notation follows from Section D.3, where $t-a$ refers to the brood year relative to the year of interest, t. Survival rates for ages 3, 4, and 5 are assumed known and constant. Using the sequence of events explained in Chapter B, the harvest rates for freshwater mainstem and terminal fisheries can be found in a similar manner.

The **Maturity Rates** are simply the percentage of fish from age n and the given stock that mature at age n. Section D.3 gives procedures that may be used to find possible input maturity rates when assuming known survival rates.

C.2.7 Stray rates

A **Stray Rate** is defined as the percentage of fish that stray to a watershed other than its natal watershed (see Table 13). These rates can be entered in the fourteen stray rate columns. Since the natal watershed would not have a stray rate, the cell for the current stock in this column is blacked out and does not need to have a number entered. All of the other cells must have a number greater than or equal to zero entered and must not sum to a number greater than 100. The percentage of fish returning to the natal watershed is automatically calculated by subtracting the sum of the stray rates from 100.

After a watershed has been entered for a stock, the stray rates are left unchanged, except the old natal watershed has the stray rate that was previously entered in the new natal watershed's stray rate cell. Subsequently, the new watershed stray rate cell is now blacked out and the old natal watershed can receive input of a stray rate, if necessary. **It is good practice to always check that the stray rates are correct after selecting a watershed.**

The estimation procedures assume no straying of natural stocks, thus natural stocks are estimated on a watershed basis. Therefore, the true production will reflect straying, and the estimation will not. However, the estimation procedures may include natural stocks that strayed to the current watershed. It may be useful to determine how straying of natural stocks can affect the accuracy and precision of the production estimates for each watershed.

Table 13: Stray Rate parameters.

Parameter	Description
Stray Rate (American R)	On average, the percentage of fish that stray to the American River watershed to spawn. These are fish that are not native to the American watershed.
Stray Rate (Battle Cr)	On average, the percentage of fish not native to Battle Creek that stray to the Battle Creek watershed to spawn.
...	...
Stray Rate (Yuba R)	On average, the percentage of fish not native to Yuba River that stray to the Yuba River watershed to spawn.

C.2.8 In-river and In-hatchery split

Hatchery Sheet Only The two remaining parameters to enter on the *Hatchery* sheet are the **% hatchery fish escaped to hatchery** and **% natural fish escaped to hatchery**. These parameters represent the average percentage of hatchery fish and natural fish, respectively, that will escape to the hatchery defined on that row. For example, if 90% of the native or straying hatchery fish that escape to the American River watershed will travel to and be counted in the hatchery, then set **% hatchery fish escaped to hatchery** to 90 for the row on the *Hatchery* sheet that represents the American watershed. There is a separate parameter for natural fish since the percentage of natural fish that are taken by the hatchery can be different than the percentage of hatchery fish taken by the hatchery. These percentages determine what is called in-hatchery escapement, as opposed to in-river escapement and applies to any fish that escapes to the watershed on which the hatchery is located. Watersheds without hatcheries will have only in-river escapement.

C.3 Starting the Simulation

Before starting a simulation, recheck that all of the data entered is correct. Also, the aging errors matrix and the spawner weights should be checked. These were explained in Section C.1 and can be found in the *Edit* menu. If alternative S1 or S2 will be run, make sure that there are releases in the stealth groups on the *Hatchery* sheet and the number of years being simulated is at least seven, unless incidental mortality errors are not wanted (see Chapter D).

After the data entry is complete, a simulation can be started from the **Run** menu, the toolbar, or by pressing the F key associated with the alternative. If alternative S1 or S2 was chosen, the user must first enter in known values of age 3, 4, and 5 survival. These values will be used when estimating incidental mortality and do not need to be the same as the survival parameters entered for any stock. See Chapter D for more information on why these values have to be pre-defined.

The simulation begins by checking for errors such as percentages greater than 100 or less than 0. If no errors were found, it runs the simulation. If errors were found, it will either report the error that must be corrected and abort the simulation, or will prompt the user for a correct entry. The user may also abort the simulation when prompted.

If there were no errors, the simulation proceeds. The workbook is hidden and only a progress window is shown. There are two progress bars that show where the simulation is. The lower bar shows the simulation running over recovery years and is reset for every outer simulation. The upper bar shows the outer simulations, which will be full when the program is complete. Notice that the recovery years progresses quickly in the very beginning, then slows down dramatically. These first few years are when the simulation is creating all of the age classes, and thus no sampling or estimation are taking place. When sampling and estimation are taking place, the progress bars may seem to freeze. It is likely that the program is still working, but the sampling is taking a long time to complete. The simulation can be aborted from here by pressing the *Abort* button, which will take you back to the workbook to enter data.

C.4 Output

When a simulation completes, two new sheets are created: *Hatchery Output* and *Natural Output*. These sheets contain the average, median, standard deviation, minimum, and maximum of the mean relative absolute prediction error (MAE) for each stock. The MAE is calculated as,

$$MAE_i = \frac{1}{recYrs} \sum_{j=1}^{recYrs} \frac{|P_{i,j} - \hat{P}_{i,j}|}{P_{i,j}}, \tag{8}$$

where $recYrs$ is the total number of recovery years, $P_{i,j}$ is the true production, and $\hat{P_{i,j}}$ is the estimated production, for simulation i and recovery year j. The statistics above are calculated over all simulations. For example, the average of the MAE is

$$\frac{\sum_{i=1}^{numSims} MAE_i}{numSims},$$

where $numSims$ is the total number of outer simulations. These statistics give an idea as to how well the estimates of production are and can be used to compare different scenarios. A larger mean or median MAE suggests that the production is not being estimated accurately, and a large standard deviation shows that the estimates of production may not be precise.

The *Natural Output* sheet also contains statistics for the ratio of the last year's production to the first year's production. These values are only reported if more than one recovery year is simulated and can be used to gauge the increase in natural production over the time period entered. The statistics for this ratio are reported for true production (not actually seen in practice, but simulated by the program) and estimated production. For example, if a doubling of natural production is wanted within a twenty year time period, these values can help to determine if there will truly be a doubling in production and if it will be detected using the estimation procedures described here. The ratio is calculated as

$$\frac{Production\ in\ final\ year}{Production\ in\ first\ year} \tag{9}$$

As explained in Chapter D, the estimate of terminal catch for alternative NS2, and the estimates of terminal catch and escapement for alternative S2 can be negative. When either of these alternatives are run, the *Natural Output* sheet will report the number of negative estimates that occurred. Alternative NS2 the number of negative estimates for escapement and terminal estimates separately, and because the selective fishery cannot take unclipped fish in the terminal harvest, only the the negative estimates of escapement are reported for alternative S2. This will help to determine how often absurd estimates are likely to occur given the parameters entered.

C.4.1 External Files

In addition, four external files are always created in the directory that the workbook is saved in, or the directory the program is in if the workbook has not been saved. These four tab delimited files are called ***Hatchery.dat***, ***Natural.dat***, ***NatProduction.dat***, and ***MAE.dat***. If a file of that name could not be written to, a number will be appended to the filename. For example, ***Natural1.dat***. A message box appears when the simulation is finished, noting the names of the files.

The two files ***Hatchery.dat*** and ***Natural.dat*** contain the true and estimated productions for all recovery years (rows) and all stocks (columns) calculated during the last outer simulation. This will give an idea as to what one simulation is like. ***Natural.dat*** also contains the recruitment for each recovery year and stock during the last simulation. This will help determine if the natural stocks are declining or increasing over time, and can be used to gauge the correctness of the spawner-recruitment parameters.

The file ***NatProduction.dat*** contains the true and estimated production summed over all natural stocks. This would be the total production of natural fish in the entire system. The rows are for each outer simulation and the columns represent each recovery year. Viewing this file will give insight into how variable the simulations are in terms of total natural production.

MAE.dat is a tab-delimited file that contains the mean relative absolute prediction error for all stocks (hatchery and natural) and all simulations. These are the numbers that are used to calculate the statistics of the MAE for each stock (reported on the *Hatchery Output* and *Natural Output* sheets).

Sometimes, all of the data generated are needed to accurately asses the results. The check boxes for **Check to Create an Output File** on the *Natural* sheet will create a file for the natural stock in that row containing important diagnostic data. The file will be named after the watershed of the same row and have *.dat* appended to it. For example, if the check box for the natural stock from, say, the American River watershed was checked, a file called ***American River.dat*** would be created in the working directory. The working directory is the folder in which the workbook is saved, or the folder the CFM Sim application is in if the workbook has not been saved.

The watershed file contains the yearly number of recruits, true catches or incidental mortality, true escapement, true production, and estimated production across the columns. The true catches when running alternatives NS1 and NS2 are the ocean and freshwater mainstem catches, and the terminal area catches for the specific watershed. Instead of catches, alternative S1 and S2 report the number of fish that suffered incidental mortality for each fishery. The terminal catches and escapements are the sum of all fish from all stocks in the category. Therefore, fish which strayed from other native watersheds will be included in the category, but native fish to the watershed that strayed to other watersheds will not be included in the terminal catches or escapement of this watershed.

The number in the column heading tells what recovery year the value is from. For example, *Recruit1* would be the number of recruits for the stock from the first recovery year, and *EstProd3* would be the estimate of the production in the third recovery year. The rows represent each simulation and are numbered from one to the number of the final simulation. Alternatives NS1 and NS2 will have headings labeled *OcCatch*, *MainCatch*, and *TermCatch*, while alternatives S1 and S2 will have the headings *OcIncMort*, *FMnIncMort*, and *TrmIncMort* for the ocean, freshwater

Table 14: Headings for the watershed specific output file of a natural stock. These files will have the name of the watershed with *.dat* appended to them.

Heading	Description
Sim #	The number of the simulation which generated the data in the row.
Recruits$n$	The number of recruits for recovery year n. These are progeny of the spawning in-river escapement from recovery year $n-1$.
OcCatch$n$	The true ocean catch for recovery year n. Only for alternatives NS1 and NS2.
MainCatch$n$	The true freshwater mainstem catch of the stock for recovery year n. Only for alternatives NS1 and NS2.
TermCatch$n$	The true terminal area catch for recovery year n. All fish only in this watershed (including strays from other stocks). Only for alternatives NS1 and NS2.
OcIncMort$n$	The true number of fish from this stock which suffered incidental mortality in the ocean fishery for recovery year n. Only for alternatives S1 and S2.
FMnIncMort$n$	The true number of fish from this stock which suffered incidental mortality in the freshwater mainstem fishery for recovery year n. Only for alternatives S1 and S2.
TrmIncMort$n$	The true number of fish in this watershed which suffered incidental mortality in the terminal area fishery for recovery year n. All fish only in this watershed (including strays from other stocks). Only for alternatives S1 and S2.
In-river$n$	The true in-river escapement of all stocks to only this watershed for recovery year n. Includes strays to this watershed.
In-hatch$n$	The true in-hatchery escapement of all stocks to only this watershed for recovery year n. Includes strays to this watershed.
TrueProd$n$	The true production for recovery year n.
EstProd$n$	The estimated production for recovery year n.

mainstem, and terminal catches or number of fish that suffered incidental mortality in the fishery. Table 14 defines each row heading.

This stock specific output file gives a close look as to how this stock is actually behaving, and how well the estimation is doing. First, looking at the number of recruits will show if the spawner-recruitment parameters are reasonable and/or if the stock is not making it back to spawn. Recruitment depends on two things: the parameters in the spawner-recruitment function and the number of spawners returning. If the recruitment is low, and driving the stock to extinction, either the spawner-recruitment parameters are not creating enough recruits or there are not enough fish escaping to spawn in-river to sustain a natural stock. Second, looking at the in-river escapement numbers will show the numbers of fish returning to spawn in the river. If these numbers seem reasonable, then either the parameters of the spawner-recruitment function are inadequate or the spawner weightings are too low for some ages, resulting in a lower relative number of spawners. Also, the catches may be too large and taking all of the fish before they even have the chance to escape. Nevertheless, these files can be created to explore the behavior of the natural stocks more closely, and should be viewed to verify that the model is simulating what is expected.

These output files are indispensable in their ability to detect problems with the parameters, determine the effects of parameters on the estimation, and see how the stocks are behaving in the simulation. These output files are tab delimited for easy viewing in text editors and other spreadsheet programs, and should be examined frequently to make sure the simulation is doing what is expected.

C.4.2 Incidental mortality output

Alternatives S1 and S2 also create one more sheet called *Incidental Mortality* when greater than 6 recovery years are simulated. Separate incidental mortality rates in the ocean, freshwater mainstem, and terminal area fisheries can not be calculated, but a difference of the expected escapement if there was no incidental mortality (or no fishery intervention with the stock) and the true observed escapement can. This is noted by D and is defined as

$$D_x = \mathrm{E}(E_x|\theta = 0) - E_x, \tag{10}$$

where x refers to the stock and θ is the probability that a fish suffers incidental mortality in any of the fisheries. The notation that $\theta = 0$ denotes that no fishery intercepted the chosen stock, or that no fish die upon release from any fishery. Therefore, D_x is an indication of how many more fish would have escaped if there was no selective fishery or all unmarked fish from stock x survived the selective fishery. See Section D.3 for a closer look at the calculation of this difference.

The *Incidental Mortality* sheet reports statistics of the mean relative absolute prediction error between the true difference, D_x, and the estimated difference $\widehat{D_x}$, similar to the *Hatchery Output* and *Natural Output* sheets. Therefore, the mean relative average prediction error of $\widehat{D}_x$ is

$$MAD_x, i = \frac{\sum_{j=1}^{Yrs} |D_{x,i,j} - \widehat{D}_{x,i,j}|}{Yrs}, \tag{11}$$

where i refers to the simulation number, j denotes the year beyond 6, and Yrs is the number of years in the simulation that the incidental mortality can be calculated. As explained in Chapter D, seven years of data are needed to estimate $\widehat{D_x}$. Therefore, Yrs in equation (11) is 6 less than the maximum number of recovery years simulated, and **Number of Years** on the *Globals* sheet must be 7 or greater for incidental mortality statistics to be calculated. If incidental mortality is not of concern, any number of recovery years can be used to estimate production in alternatives S1 and S2. Chapter D describes the incidental mortality in greater detail.

D Production Estimates

Newman (2000) explained how to estimate the production for alternatives NS1, NS2, S1, and S2, assuming no terminal fishery for the non-selective fishery alternatives and only an ocean fishery for the selective fishery alternatives. CFM Sim has the ability to estimate production for the four alternatives when freshwater mainstem and terminal fisheries are present. The estimation procedures are outlined in this chapter for the four alternatives.

D.1 Alternative NS1

Recall that there is no selective fishery, there are four categories of fish released at each hatchery, and simple random samples are taken of ocean catch and freshwater mainstem catch, as well as the terminal catch and escapement of each watershed. For simplicity the geometry of the freshwater system is viewed as a single "mainstem" section that ends with branches to several "watersheds", where terminal fisheries and escapement occur. The constant fractional marking rate is denoted c.

Estimating Hatchery Specific Production

Newman (2000) derived the equations to estimate the ocean catch, freshwater mainstem catch, and escapement of a hatchery stock. The estimate of terminal harvest is similar to estimating the escapement. For terminal harvest and escapement estimation it is *assumed* that hatchery fish can return to any watershed (in addition to the one the natal hatchery is located in). Let $ta_{i,j}$, $tb_{i,j}$, and $tc_{i,j}$ be the number of sample recoveries from the experimental and *ad hoc* group, surrogate group(s), and the constant fractional marked group, respectively, in watershed j. Then,

$$\widehat{C}_{T,hi} = \sum_{j=1}^{k} \frac{\widehat{C}_{T_j}}{n_{T_j}} \left(ta_{i,j} + tb_{i,j} + \frac{tc_{i,j}}{c} \right). \tag{12}$$

$\widehat{C}_{T_j}$ is the estimate of the total terminal harvest for the season in watershed j , and n_{T_j} is the size of the sample taken from the total terminal harvest in watershed j.

Estimating Watershed Specific Natural Production

Since it is assumed that the natural fish do not stray to any watershed, it is quite simple to estimate the watershed specific natural terminal harvest and escapement. Because all hatchery fish have at least an ad-clip, any fish in the terminal catch or escapement without an ad-clip should be a natural fish. Let tn be the number of unclipped fish, thus natural fish, in the terminal harvest sample and zn be the number of unclipped fish observed in the escapement sample. Then the estimates of natural terminal harvest and natural escapement to watershed j are

$$\widehat{C}_{T,nj} = \frac{\widehat{C}_{T_j}}{n_{T_j}} tn_j \tag{13}$$

$$\widehat{E}_{nj} = \frac{\widehat{E}_j}{n_{E_j}} zn_j. \tag{14}$$

The ocean and freshwater mainstem catches of natural stock j are estimated using the hatchery surrogates and the escapement estimates, as outlined in Newman (2000). The intuition behind the estimate of $C_{O,nj}$ can be seen by substituting expected values for the estimated values on the right hand side of the equation.

$$\begin{aligned}\sum_{a=2}^{5} \widehat{C}_{O,hi,a} \frac{\widehat{E}_{nj,a}}{\widehat{E}_{hi,a}} &\approx \sum_{a=2}^{5} \mu_{O,a} N_{bi,a} \frac{(1-\mu_{O,a})\sigma_a(1-\mu_{F,a})(1-\mu_{T,a})N_{nj,a}}{(1-\mu_{O,a})\sigma_a(1-\mu_{F,a})(1-\mu_{T,a})N_{bi,a}} \\ &= \sum_{a=2}^{5} \mu_{O,a} N_{nj,a}\end{aligned}$$

where $N_{bi,a}$ and $N_{nj,a}$ are the abundances of age a fish from hatchery surrogate i and natural stock j prior to harvest. It is important to understand this relationship because if the harvest rates in the numerator and denominator are not equal, as assumed here, the catches will be biased. For example, if all natural fish return to their native watershed and are subject to a terminal fishery, and their hatchery surrogates can stray to a watershed that does not have a terminal fishery, the denominator will be larger than expected, thus underestimating the catch. Since the production of a natural stock is the sum of the estimated catches and escapement,

$$\widehat{P}_{nj} = \widehat{C}_{O,nj} + \widehat{C}_{F,nj} + \widehat{C}_{T,nj} + \widehat{E}_{nj}, \tag{15}$$

the assumption that the natural stock and its surrogate behave in the same way is crucial to estimate the production without bias. A similar argument applies to the estimation of $C_{F,nj}$.

D.2 Alternative NS2

Recall that there is no selective fishery and not all hatchery fish are marked.

Estimating Hatchery Specific Production

The estimates of ocean catch, freshwater catch, terminal catch, and escapement of hatchery releases are identical to alternative NS1 since the remaining release group of fish is estimated by expanding the CFM group recoveries.

Estimating Watershed Specific Natural Production

Estimation of natural terminal catch and escapement to a given watershed differs from alternative NS1 in that estimates of hatchery terminal catch or escapement to the watershed are subtracted from the estimate of total terminal catch or escapement. Assuming that there are r hatchery stocks that contribute to the escapement in watershed j,

$$\widehat{C}_{T,nj} = \widehat{C}_{T_j} - \sum_{i=1}^{r} \widehat{C}_{T_{hi,j}} \tag{16}$$

$$\widehat{E}_{nj} = \widehat{E}_j - \sum_{i=1}^{r} \widehat{E}_{hi,j} \tag{17}$$

where

$$\widehat{C}_{T,hi,j} = \frac{\widehat{C}_{T_j}}{n_{C_{T_j}}}(ta_{i,j} + tb_{i,j} + \frac{tc_{i,j}}{c}), \text{ and}$$

$$\widehat{E}_{hi,j} = \frac{\widehat{E}_j}{n_{E_j}}(za_{i,j} + zb_{i,j} + \frac{zc_{i,j}}{c}).$$

The catches of the natural stock in the ocean and freshwater mainstem fisheries are estimated the same as alternative NS1. Newman (2000) shows how the natural escapement can be estimated by subtracting the unmarked hatchery fish from the total number of unmarked fish.

D.3 Alternative S1

Recall that a selective fishery is assumed and there are five categories of hatchery releases including a stealth group.

It is assumed that all unmarked fish in hatchery and escapement samples are scanned for CWTs, thus recoveries from the stealth group are identified. It is further assumed that the selective fisheries do not retain any unmarked fish, but some unmarked fish will die after being caught and released. This is called incidental mortality.

Estimating Hatchery Specific Production

The estimates of hatchery specific ocean ($\widehat{C}_{O,hi}$), mainstem ($\widehat{C}_{F,hi}$), and terminal ($\widehat{C}_{T,hi}$) harvests are the same as the alternative NS1 harvest equations. The "stealth" group can not be kept in the fishery, thus does not appear in the catch sample. The expansion of the CFM recoveries remains appropriate because the harvest rate on the ad-clipped only members of the release should be the same as for the CFM group.

The estimate of hatchery specific escapement, $\widehat{E}_{hi}$, is also identical to the alternative NS1. The data collection procedure differs, however, in that all unmarked fish in the escapement sample must be scanned, killing those with tags or a subset of them, assuming they are not dead already.

Estimating Watershed Specific Natural Production

No natural fish are kept in a selective fishery, thus natural production consists of only escapement. To estimate the natural escapement to watershed j, again assume no straying of natural fish to other watersheds. Because of stealth groups some escapement sample recoveries will include hatchery fish without ad-clips. Assuming all unclipped fish are scanned for CWTs, however, the number of unclipped fish without CWTs are presumably natural fish and equation (14) can be used.

In a selective fishery natural fish will not be retained, but there will certainly be fishing induced mortality (also called shaker or incidental mortality). This mortality is of interest to fisheries managers for several reasons, including knowing the impact on natural stocks. The fishery and age specific incidental mortalities can not be separately estimated because there are more unknown variables than known variables. However, a difference of the expected escapement if there was no incidental mortality (or no fishery intervention with the stock) and the actual escapement can be calculated. This is denoted by D and is defined as

$$D = \mathrm{E}(E|\theta = 0) - E, \tag{18}$$

where θ is the probability that a fish suffers incidental mortality in any of the fisheries. The notation that $\theta = 0$ indicates that no fishery intercepted the chosen stock, or that no fish die upon release from any fishery. Therefore, D is an indication of how many more fish would have escaped if there was no selective fishery or all unmarked fish survived the selective fishery.

To estimate this measure of mortality ($\hat{D}$), we either *assume* that the maturation rates for all ages are known and constant or that natural survival rates for ages 3, 4, and 5 are known and constant. There may be ways to avoid assuming known maturation or survival rates, but some other parameters will likely have to be assumed known, as the estimation procedures given below suggest. The methods of estimation when assuming known and constant maturation rates are not discussed here, but how to calculate $\hat{D}$ when assuming natural survival rates are known and constant, is shown next.

Unfortunately, the notation is unavoidably cumbersome. The year of interest is set equal to t. Catches (C) and escapements (E) have three subscripts. The first is either b for the surrogate group or d for the stealth group. The second is age of the fish, a= 2, 3, 4, or 5. The third subscript is the brood year of the caught or escaping fish relative to the year of interest. For example, $C_{b,4,t-5}$ is the catch of age 4 surrogate fish from a release of brood year five years earlier, namely last year's age 4 catch. Or $C_{d,5,t-2}$ is the catch of age 5 stealth fish from a release of brood year two years ago, which would actually be the catch 3 years into the future if t is the current year.

Calculating $\mathrm{E}(E|\theta = 0)$ simply involves multiplying the release size by survival and maturity rates, thus not applying any of the harvest probabilities to the stock (equations (20-23)). It is important to use the correct brood year for the different age classes, hence, the inclusion of the brood year notation.

Release numbers (R) have two subscripts, the first being either b or d and the second being the brood year relative to the year of interest. Harvest rates μ_O, μ_F, and μ_T are first subscripted b or d, then by age at harvest, and then by brood year relative to the year of interest. Survival rates are subscripted first by I, 3, 4, or 5 and then the brood year relative to the year of interest. The symbol P_F, with the same subscripts, denotes the sum of all of the freshwater observations for stock x, including freshwater mainstem catch, terminal area catch, and escapement.

$$P_{F,b,a,t-a} = C_{F,b,a,t-a} + C_{T,b,a,t-a} + E_{F,b,a,t-a}$$

Survival rates, S_3, S_4, and S_5, are known and constant.

$$\widehat{D}_{d,t-a} = \sum_{a=2}^{5} \left[\widehat{\mathrm{E}}(E_{d,a,t-a}) - \widehat{E}_{d,a,t-a} \right] \tag{19}$$

$$\widehat{\mathrm{E}}(E_{d,2,t-2}|\theta = 0) = R_{d,t-2}\widehat{S}_{I,t-2}(1 - \hat{\sigma}_{2,t-2}) \tag{20}$$

$$\widehat{\mathrm{E}}(E_{d,3,t-3}|\theta = 0) = R_{d,t-3}\widehat{S}_{I,t-3}(1 - \hat{\sigma}_{2,t-3})S_3\hat{\sigma}_{3,t-3} \tag{21}$$

$$\widehat{\mathrm{E}}(E_{d,4,t-4}|\theta = 0) = R_{d,t-4}\widehat{S}_{I,t-4}(1 - \hat{\sigma}_{2,t-4})S_3(1 - \hat{\sigma}_{3,t-4})S_4\hat{\sigma}_{4,t-4} \tag{22}$$

$$\widehat{\mathrm{E}}(E_{d,5,t-5}|\theta = 0) = R_{d,t-5}\widehat{S}_{I,t-5}(1 - \hat{\sigma}_{2,t-5})S_3(1 - \hat{\sigma}_{3,t-5})S_4(1 - \hat{\sigma}_{4,t-5})S_5 \tag{23}$$

$$\widehat{S}_{I,t-2} = \frac{\widehat{C}_{O,b,2,t-2} + \widehat{P}_{F,b,2,t-2} + \frac{\widehat{C}_{O,b,3,t-2} + \widehat{P}_{F,b,3,t-2} + \frac{\widehat{C}_{O,b,4,t-2} + \widehat{P}_{F,b,4,t-2} + \frac{\widehat{C}_{O,b,5,t-2} + \widehat{P}_{F,b,5,t-2}}{S_5}}{S_4}}{S_3}}{R_{b,t-2}} \tag{24}$$

$$\widehat{S}_{I,t-3} = \frac{\widehat{C}_{O,b,2,t-3} + \widehat{F}_{b,2,t-3} + \frac{\widehat{C}_{O,b,3,t-3} + \widehat{P}_{F,b,3,t-3} + \frac{\widehat{C}_{O,b,4,t-3} + \widehat{P}_{F,b,4,t-3} + \frac{\widehat{C}_{O,b,5,t-3} + \widehat{P}_{F,b,5,t-3}}{S_5}}{S_4}}{S_3}}{R_{b,t-3}} \tag{25}$$

$$\widehat{S}_{I,t-4} = \frac{\widehat{C}_{O,b,2,t-4} + \widehat{F}_{b,2,t-4} + \frac{\widehat{C}_{O,b,3,t-4} + \widehat{P}_{F,b,3,t-4} + \frac{\widehat{C}_{O,b,4,t-4} + \widehat{P}_{F,b,4,t-4} + \frac{\widehat{C}_{O,b,5,t-4} + \widehat{P}_{F,b,5,t-4}}{S_5}}{S_4}}{S_3}}{R_{b,t-4}} \tag{26}$$

$$\widehat{S}_{I,t-5} = \frac{\widehat{C}_{O,b,2,t-5} + \widehat{F}_{b,2,t-5} + \frac{\widehat{C}_{O,b,3,t-5} + \widehat{P}_{F,b,3,t-5} + \frac{\widehat{C}_{O,b,4,t-5} + \widehat{P}_{F,b,4,t-5} + \frac{\widehat{C}_{O,b,5,t-5} + \widehat{P}_{F,b,5,t-5}}{S_5}}{S_4}}{S_3}}{R_{b,t-5}} \tag{27}$$

$$\hat{\sigma}_{2,t-2} = \frac{\widehat{P}_{F,b,2,t-2}}{R_{b,t-2}\widehat{S}_{I,t-2} - \widehat{C}_{O,2,t-2}} \tag{28}$$

$$\hat{\sigma}_{2,t-3} = \frac{\widehat{P}_{F,b,2,t-3}}{R_{b,t-3}\widehat{S}_{I,t-3} - \widehat{C}_{O,2,t-3}} \tag{29}$$

$$\hat{\sigma}_{2,t-4} = \frac{\widehat{P}_{F,b,2,t-4}}{R_{b,t-4}\widehat{S}_{I,t-4} - \widehat{C}_{O,2,t-4}} \tag{30}$$

$$\hat{\sigma}_{2,t-5} = \frac{\widehat{P}_{F,b,2,t-5}}{R_{b,t-5}\widehat{S}_{I,t-5} - \widehat{C}_{O,2,t-5}} \tag{31}$$

$$\hat{\sigma}_{3,t-3} = \frac{\widehat{P}_{F,b,3,t-3}}{[R_{b,t-3}\widehat{S}_{I,t-3} - (\widehat{C}_{O,b,2,t-3} + \widehat{P}_{F,b,2,t-3})]S_3 - \widehat{C}_{O,b,3,t-3}} \tag{32}$$

$$\hat{\sigma}_{3,t-4} = \frac{\widehat{P}_{F,b,3,t-4}}{[R_{b,t-4}\widehat{S}_{I,t-4} - (\widehat{C}_{O,b,2,t-4} + \widehat{P}_{F,b,2,t-4})]S_3 - \widehat{C}_{O,b,3,t-4}} \tag{33}$$

$$\hat{\sigma}_{3,t-5} = \frac{\widehat{P}_{F,b,3,t-5}}{[R_{b,t-5}\widehat{S}_{I,t-5} - (\widehat{C}_{O,b,2,t-5} + \widehat{P}_{F,b,2,t-5})]S_3 - \widehat{C}_{O,b,3,t-5}} \tag{34}$$

$$\hat{\sigma}_{4,t-4} = \frac{\widehat{P}_{F,b,4,t-4}}{\left[[R_{b,t-4}\widehat{S}_{I,t-4} - (\widehat{C}_{O,b,2,t-4} + \widehat{P}_{F,b,2,t-4})]S_3 - (\widehat{C}_{O,b,3,t-4} + \widehat{P}_{F,b,3,t-4})\right] S_4 - \widehat{C}_{O,b,4,t-4}} \tag{35}$$

$$\hat{\sigma}_{4,t-5} = \frac{\widehat{P}_{F,b,4,t-5}}{\left[[R_{b,t-5}\widehat{S}_{I,t-5} - (\widehat{C}_{O,b,2,t-5} + \widehat{P}_{F,b,2,t-5})]S_3 - (\widehat{C}_{O,b,3,t-5} + \widehat{P}_{F,b,3,t-5})\right] S_4 - \widehat{C}_{O,b,4,t-5}} \tag{36}$$

Note that negative estimates of $\widehat{D}$ for the stealth fish are possible. The probability of negative estimates will increase as errors in catch and escapement estimates worsen.

The data requirements in terms of which years of catch and escapement data are needed is a limiting factor of this approach. When assuming known survival rates for ages 3, 4, and 5, data for the preceding three years, the current year, and the next three years are required. Assuming known maturation may be less restrictive on the data requirements, but it is more likely to obtain better survival estimates than maturation estimates.

However, neither assuming known maturation rates nor assuming known survival rates (age 3, 4, or 5) is a desirable assumption. Both maturation rates and survival rates are likely to vary naturally within cohorts of the same stock and between different stocks. One possibility is to specify a probability distribution for the "known" set of survival rates and then randomly sample from that distribution and compute different estimates of the above parameters, which will then partially reflect the uncertainty in the estimates (Newman 2000).

The expected escapement in the the absence of all fisheries, of the natural stock represented by the stealth group can be estimated using equation (19) and age-specific estimates of the natural stock and stealth group escapements.

$$\widehat{\mathrm{E}}(E_{n,a,t-a}|\theta = 0) \quad = \quad \frac{\widehat{\mathrm{E}}(E_{d,a,t-a}|\theta = 0)}{\widehat{E}_{d,a,t-a}} \widehat{E}_{n,a,t-a} \tag{37}$$

The age-specific natural stock escapement estimates, $\widehat{E}_{n,a,t-a}$, would be calculated as described in Newman (2000).

Therefore, the age-specific escapement estimates and estimate of the expected escapement can be used to estimate the decrease in escapement due to the selective fisheries.

$$\widehat{D}_{n,t-a} = \sum_{a=2}^{5} \left[\widehat{\mathrm{E}}(E_{n,a,t-a}|\theta = 0) - \widehat{E}_{n,a,t-a}\right] \tag{38}$$

D.4 Alternative S2

Recall that a selective fishery is assumed to take place and that the 1-c% "remainder" of the hatchery releases are unmarked and untagged, thus subject to incidental mortality.

Estimating Hatchery Specific Production

The estimates are similar to those of S1, except that expansions for the $1-c$% remainder (unmarked fish) are not made in the catch estimates since unmarked fish are not kept. However, estimates of unmarked hatchery fish in the escapement sample are needed (Newman 2000). The watershed specific terminal harvest can then be estimated with equation (39).

$$\widehat{C}_{T,hi} \quad = \quad \sum_{j=1}^{k} \frac{\widehat{C}_{T_j}}{n_{C_{T_j}}} \left(ta_{i,j} + tb_{i,j} + tc_{i,j}\right) \tag{39}$$

where ta, tb, and tc, refer to *ad hoc*, *surrogate*, and *CFM* groups for terminal area catches.

Estimating Watershed Specific Natural Production

Estimation of natural escapement to a given watershed is found by first estimating the total escapement of unmarked fish, which includes natural fish, unmarked and untagged hatchery fish, and unmarked but tagged hatchery fish (stealth). The estimate of unmarked and stealth hatchery fish is then subtracted from this estimate to obtain the natural escapement. See Newman (2000) for a more detailed discussion.

The estimate of D_d can be found using equations (19)–(36). However, estimates of the fishing induced mortality on stealth and the unmarked and untagged hatchery releases, $\widehat{D}_{d+u,i}$, can estimated using the assumption implied earlier that the stealth group and the unmarked and untagged group have the same life history parameters.

$$\widehat{D}_{d+u,t-a} = \sum_{a=2}^{5}\left[\widehat{\mathrm{E}}(E_{d+u,a,t-a}|\theta=0) - \left(\widehat{E}_{d,a,t-a} + \widehat{E}_{h,u,a,t-a}\right)\right] \quad (40)$$

$$\widehat{\mathrm{E}}(E_{d+u,2,t-2}|\theta=0) = (R_{d,t-2} + R_{u,t-2})\widehat{S}_{I,t-2}(1-\hat{\sigma}_{2,t-2}) \quad (41)$$

$$\widehat{\mathrm{E}}(E_{d+u,3,t-3}|\theta=0) = (R_{d,t-3} + R_{u,t-3})\widehat{S}_{I,t-3}(1-\hat{\sigma}_{2,t-3})S_3\hat{\sigma}_{3,t-3} \quad (42)$$

$$\widehat{\mathrm{E}}(E_{d+u,4,t-4}|\theta=0) = (R_{d,t-4} + R_{u,t-4})\widehat{S}_{I,t-4}(1-\hat{\sigma}_{2,t-4})S_3(1-\hat{\sigma}_{3,t-4})S_4\hat{\sigma}_{4,t-4} \quad (43)$$

$$\widehat{\mathrm{E}}(E_{d+u,5,t-5}|\theta=0) = (R_{d,t-5} + R_{u,t-5})\widehat{S}_{I,t-5}(1-\hat{\sigma}_{2,t-5})S_3(1-\hat{\sigma}_{3,t-5})S_4(1-\hat{\sigma}_{4,t-5})S_5 \quad (44)$$

The age-specific stealth group and unmarked, untagged escapements, $\widehat{E}_{d,a}$ and $\widehat{E}_{h,u,a}$, can be estimated as described in Newman (2000).

$$\widehat{E}_{d,a,t-a} = \sum_{j=1}^{k}\frac{\widehat{E}_j}{n_{E_j}} zd_{i,j,a,t-a} \quad (45)$$

$$\widehat{E}_{u,a,t-a} = \frac{R_{u,t-a}}{R_{d,t-a}}\widehat{E}_{d,a,t-a} \quad (46)$$

The notation can become confusing, but it is important to use the correct brood year relative to the age or year the estimate is for.

To estimate the fishing induced mortality on the natural stock, first find $\widehat{\mathrm{E}}(E_{n,a,t-a}|\theta=0)$ as in equation (37). The age specific natural escapement estimate, $\widehat{E}_{n,a}$, can be found with a similar procedure that alternative NS2 applies. The difference in escapement due to the selective fishery can now be found with equation (38).

E Additional Details of Simulation and Estimation

Each simulation in CFM Sim follows the sequence of events described in Section B.2. This chapter will describe this sequence in detail.

Immediately after starting a simulation, the program will first check for errors in the data entry. This includes checking that rates are entered as percentages between 0 and 100, that the **min**, **mode**, and **max** of parameters are in fact the minimum, mode, and maximum, and that data that must be entered is entered. If the program detects an error, it will display a message, which sometimes will allow the user to change the parameter without aborting the simulation. The program can be aborted from these message boxes, and sometimes the program automatically aborts after reporting the error.

E.1 Simulation of Survival, Harvest, and Maturation Processes

Once all of the errors have been fixed, the sequence of events explained in Section B.2 is simulated, namely survival, harvest, and maturation processes. Figures 1 and 2 give a visual depiction of the sequence and some of the terms used herein to describe the process of the program. Since there are ages 2 through 5 present in the simulation, the program must begin three recovery years before the initial recovery year to build up the age classes. In other words, the first recovery year simulates only age two fish. The second recovery year uses the age two fish that were still available in the ocean to step through a sequence of survival, harvest, maturation, and escapement for age 3 fish and simulates a new sequence of age 2 fish. Then age 4 fish are derived from age 3 fish and so on. Finally, recording of the production begins when age 5 fish are being simulated.

Each recovery year begins by drawing random quantiles from a uniform distribution between zero and one for survival, ocean harvest, freshwater harvests (mainstem and terminal), and maturity parameters. These quantiles will be used to draw a value from the triangle distributions of each respective parameter for all hatchery and natural stocks. This simulates similar trends in survival, harvest, and maturity for each stock per recovery year, as if environmental conditions or management decisions were affecting all of the stocks in a similar manner. The parameters for each stock will not be the same though, as this quantile is used to determine from where in the triangle distribution the parameter will be drawn. For example, if the survival quantile is low, the survival will be low for each respective stock. But, some stocks may have a low survival of 8% while others have a low survival of 2%.

Using the randomly generated parameters, the fates of each age class for one stock are simulated separately, beginning with the oldest age present. Hatchery stocks are simulated first, followed by natural stocks. Assuming that all of the age classes have been built up, each recovery year would begin with age 5 fish. Using the number of fish still in the ocean at the end of the previous age (before overwinter survival of the current age class) a binomial random number routine generates the number of fish that survive to the the current age, based on the survival probability. Those surviving fish are then passed to a multinomial random number generator which determines the number of fish that fall into the categories: caught in the ocean fishery, survive the ocean fishery and mature, survive the ocean fishery and don't mature ("still in ocean"). The "still in ocean" fish are stored for use in the next recovery year. The maturing fish are passed into a freshwater mainstem routine that uses a binomial random number generator to determine the number of fish that are caught in the mainstem fishery. The number of fish that survive past the mainstem fishery are divided into the 14 watersheds using a multinomial random number generator with probabilities based on the straying rates entered. Then, the fates in each watershed are determined separately. See Figure 2 for a depiction of the sequence of events in the terminal watershed.

The fish that enter a watershed will either be caught in the terminal fishery, escape to the hatchery, or escape in-river. The number of fish in these three fates is again determined with a multinomial random number generator, where the probabilities are

$$\begin{aligned} \text{Terminal Fishery Catch:} \quad P(C_{T,j,a}) &= \mu_{T,j,a} \\ \text{Hatchery Escapement:} \quad P(E_{r,j,a}) &= (1-\mu_{T,j,a})(1-\eta_j) \\ \text{In-river Escapement:} \quad P(E_{q,j,a}) &= (1-\mu_{T,j,a})\eta_j. \end{aligned}$$

The notation follows from that described in Table 6. This completes the partitioning of the fish into all of the fates for the stock. Once all of the stocks have finished, and if the initial recovery year has been reached (all age classes are present), estimation will be performed. But, before estimation procedures are explained, the spawner-recruitment curve will be mentioned.

E.2 Generation of Spawners and Recruitment

A choice of spawner-recruitment curves is offered to incorporate the dynamics of a natural stock. As defined in Section C.2.2, there are four choices for the spawner-recruitment function: Constant, Linear, Ricker, and Beverton-Holt. Different parameters for the chosen function can be entered for each natural stock, but only one function can be chosen to be applied to all natural stocks.

The entered total recruits of the natural stock are used until all ages are present in the escapement, that is, all age classes have been simulated. After that, the spawner-recruitment curve is used to calculate the recruits of natural fish. The spawning stock in watershed j is defined as

$$S_j = \omega_2 E_{r,j,2} + \omega_3 E_{r,j,3} + \omega_4 E_{r,j,4} + E_{r,j,5}, \tag{47}$$

where $E_{r,j,a}$ refers to all fish that escaped in-river, including hatchery fish. ω_a refers to the spawner weight for age class a, which is the percent contribution of a female spawner in age class a to next year's recruits, relative to an age 5 female (also see Section C.1.2). This means, if an age 4 female contributes 80% the number of recruits that an age 5 female would contribute, ω_4 would be 0.8. If an age class does not contribute to next year's recruits, say, if age 2 fish are comprised completely of males, the weight for that age would be zero. Caution: if the spawner weights are changed in the program, the spawner-recruitment parameters may have to be changed to accurately portray the correct relationship. For example, if the age 3 and 4 weights are greater than 1, the curve may have to compensate for the fact that the calculated spawners, S_j, would be greater than the actual escapement. The output files discussed in Section C.4 can be used to check that the recruitment is realistic.

The spawning stock, S_j, includes only fish that escaped in-river in watershed j. However, this may include hatchery fish and hatchery or natural fish that strayed to this watershed, depending on the parameters entered.

E.3 Sampling

When all of the abundances in the age groups have been generated and the fish harvested, sampling of the ocean harvest, mainstem harvest, watershed specific terminal harvests, and watershed specific escapements takes place. As mentioned in Section B.3, the samples are assumed to be simple random samples. The sample size is determined by multiplying the true (simulated) total harvest or escapement by the sampling rate for that fate. This total is summed over all stocks, tag groups, and ages. If the sample size is less than 10, a new sample size is set that will be either 10 or the total harvest or escapement, whichever is less. This eliminates some problems that occur when there are very small sample sizes. A simple random sample (without replacement) is taken from the total, keeping track of the stock, tag group, and age class which the fish are from. The probability of a particular group (stock, tag group, and age) is simply the number of fish in that group divided by the total harvest or escapement, whichever is being sampled. This results in a sample of fish divided into groups representing the stock, tag group, and age class.

These samples of the harvests or escapements (in-hatchery and in-river are separate) are the fish that will be checked for tags and, in the case of unmarked escapement, subject to aging. It is assumed that there is no error in identifying tags, which may be the case in the future with new tagging operations. However, it is possible that aging errors can occur. Therefore, an aging error matrix can be set to depict errors that may occur when aging fish (also see C.1.2).

E.3.1 Aging

The *Edit* menu contains the command to open a window containing the aging errors matrix. As discussed in Section C.1.2, the probability of classifying a fish of age a given its true age can be entered in this matrix. Section C.2.2 mentions the **Aging Sampling Rate**, which determines the percentage of fish from the escapement sample that are sampled for aging purposes.

During sampling of the escapement, all of the unmarked in-river or in-hatchery fish are separately pooled, since they are indistinguishable by stock, tag group, or age. A simple random sample without replacement is taken of this pooled group, with the sample size determined by multiplying the total by the **Aging Sampling Rate** from the *Globals* sheet. This sample is called the "true ages", which are multiplied by the aging error matrix as in equation (2). In the program, though, only ages 3, 4, and 5 are applied to the aging errors matrix. These ages are then extrapolated up based on the aging sampling rate and are used as the number of unmarked fish that are age a in the sample of in-river or in-hatchery escapement. The number of fish classified as age 2 are determined by subtracting the sum of the number of fish classified as ages 3, 4, and 5 from the total sample size to ensure that the sum of all ages of unmarked fish after applying the error matrix and rounding to whole numbers equals the sum of true ages of unmarked fish in the original sample.

Therefore, sampling error is applied to the aging of the fish when the simple random sample from the escapement sample is taken. To eliminate sampling error, set **Aging Sampling Rate** to 100%. Measurement error is applied when multiplying the aging error matrix to the true ages as in equation (2). To eliminate the measurement error, click on the *No Error* button in the Aging Errors window. See Section C.1.2 for detailed information on entering the aging error matrix probabilities.

E.4 Estimates of the Total Harvests and Escapement

The estimation procedures explained in Chapter D require values for the estimates of total ocean, freshwater mainstem, and terminal area harvests, as well as for escapements. Simplified, but conservative, sampling procedures were *assumed* to allow a variance of the estimate to be calculated based on the sampling rate and size of the fishery or escapement.

E.4.1 Variance of the Total Ocean Harvest

The ocean harvest is made up of two components: commercial and recreational catches. Commercial catches are known without error: i.e. counts from fish tickets are error free. However, recreational fishery catches are estimated with error. A simple random sample of anglers for the entire season over all areas is assumed for the recreational fishery, although a stratified sampling method is likely to be used. The simple random sampling method will result in a conservative estimate of the variance.

Assuming the above scheme, the total ocean harvest is estimated as follows.

$$\widehat{C}_O = \sum_{i=1}^{B_c} y_{i,c} + \frac{B_r}{b_r}\sum_{i=1}^{b_r} y_{i,r}, \tag{48}$$

where the subscript c refers to the commercial fishery, the subscript r refers to the recreational fishery, and B_c is the total number of boats in the commercial fishery and B_r is the total number of anglers in the recreational fishery. An exhaustive sample of the commercial fishery is assumed, therefore only the recreational fishery has a sample size (or number of anglers sampled), noted with b_r. Finally, y_i refers to the number of fish caught by the i'th boat or angler. The variance of the total ocean catch would be,

$$Var(\widehat{C}_O) = 0 + \left(\frac{B_r}{b_r}\right)^2 \left(\frac{B_r - b_r}{B_r}\right) \sum_{i=1}^{b_r} Var(y_{i,r}), \tag{49}$$

$y_{i,r}$ is assumed to be distributed as a Poisson random variable, with mean and variance, λ_r, equal to $\frac{C_{O,r}}{B_r}$, where $C_{O,r}$ is the total number of fish caught in the ocean recreational fishery. λ_r is then the average number of fish caught per angler in the recreational fishery. The variance is,

$$\begin{aligned} Var(\widehat{C}_O) &= \left(\frac{B_r}{b_r}\right)^2 \left(\frac{B_r - b_r}{B_r}\right) b_r \lambda_r && (50)\\ &= \frac{B_r}{b_r}(B_r - b_r)\frac{C_{O,r}}{B_r} && (51)\\ &= \left(\frac{1}{f_r} - 1\right) C_{O,r}, && (52) \end{aligned}$$

where f_r is the sampling rate of the recreational fishery (or the percentage of anglers that are sampled out of all the anglers recreational fishing over the season). The variance of the total ocean catch is now dependent on the sampling rate and the true size of the catch. This explains why **Sampling Rate of the Ocean Sport Catch** and **% of Total Ocean Catch from the Sport Fishery** must be entered on the *Globals* sheet.

The Poisson distribution assumes that all anglers are fishing with equal skill and on average would each catch the same number of fish. The domain of the distribution is zero to infinity, but the probability of a number greater than 3, when λ=1, is less than 2%. This allows the use of this distribution when in reality, anglers may be limited by catch regulations.

E.4.2 Variance of the Total Freshwater Mainstem Harvest

The freshwater mainstem harvest variance is calculated in much the same way as the variance for the total ocean harvest, but consists of only one component: recreational catches. However, since commercial catches in the total ocean harvest are assumed to be known the variance calculation of $\widehat{C}_F$ is identical to equations (50)–(52). A simple random sampling scheme, for the entire season over all areas, is assumed for the mainstem fishery, resulting in a conservative estimate of the variance.

$$Var(\widehat{C}_F) = \left(\frac{1}{f_f} - 1\right) C_F, \tag{53}$$

where f_f is the sampling rate of the total number of anglers over the fishing season in the freshwater mainstem.

E.4.3 Variance of the Watershed Specific Terminal Area Harvest

The freshwater terminal area harvest is watershed specific, thus the variance must be calculated separately for each watershed. The terminal area harvest variance for watershed j is calculated exactly as the freshwater mainstem variance in equation (53).

$$Var(\widehat{C}_{T_j}) = \left(\frac{1}{f_{t,j}} - 1\right) C_{T_j}, \tag{54}$$

where $f_{t,j}$ is the sampling rate of the total number of anglers over the fishing season in the terminal harvest of watershed j.

E.4.4 Variance of the Escapement

The escapement may be split into in-hatchery escapement and in-river escapement (Section). The hatcheries are assumed to have an accurate count on the total number of fish entering the hatchery, thus there is no variance on the total number of fish that escape to the hatchery. However, a percentage of those fish may be sampled for marks and/or tags. The in-river escapement estimates do have variability, however.

Most watersheds on the Sacramento-San Joaquin river system use some type of mark-recapture system to estimate the number of fish which escaped to the river. The Petersen estimator is assumed for calculating the variance because it would be conservative compared to other mark-recapture methods. However, the Petersen estimator is an unrealistic choice, although simple, because of the violation of assumptions such as a closed population. Nevertheless, it will result in a conservative estimate and is reasonable to use in this case. The variance of the in-river escapement for watershed j, using the Petersen estimator is

$$Var(\hat{E}_j) = \frac{(M+1)^2(C+1)(C-R)}{(R+1)^2(R+2)}. \tag{55}$$

M is the number of fish in the mark-recapture experiment that were marked out of the total escapement E_j (and examined for hatchery marks or tags). C is the number of fish re-examined for mark-recapture marks out of E_j, and R is the number of mark-recapture marks found in the recapture sample. If M and C are known, the program simulates E_j and can find R using the equation

$$R = \frac{(M+1)(C+1)}{E_j} - 1,$$

which assumes that the ratio of marked fish to unmarked fish is the same in the total population and in the recapture sample. The parameter **In-River Escapement Sampling Rate** is used to calculate M, and C is assumed to be the same as M. Although the Petersen estimator is an unrealistic choice as far as estimating the escapement in a watershed, it results in a conservative estimate of the variance which decreases with an increased sample size, and is suitable for this simulation. Other, more accurate estimators should be used in practice.

E.4.5 Calculating the Estimates of Harvest and Escapement

Now that the variances are calculated, the estimate of the total harvest or escapement can be determined. A truncated normal distribution is used to find this estimate, given the calculated variance from above and the true total harvest or escapement generated by the simulation. A normal random deviate with a mean equal to the true total harvest or escapement and variance calculated above is generated. If this "estimate" is greater than the sample size of the harvest or escapement, then it is kept as the estimate of the harvest or escapement. If it is less than the sample size, the estimate is set equal to the sample size. In light of the possibility that an estimate can be generated as less than the sample size, it will actually occur a very small percentage of the time since the variance is a function of the sampling rate and true total. As the sampling rate gets larger or the true total get smaller, the variance decreases. The estimate should be a realistic representation of what may actually occur in practice.

Estimates of the terminal harvest and the in-river escapement are calculated separately per watershed.

E.5 Estimation of the Production

Finally, the stock specific estimates of the harvests and escapement can be calculated. Hatchery stocks are estimated first, followed by the natural stocks. The calculation of these estimates are explained in Chapter D.

While the estimation procedures are occurring, the program keeps track of the number of negative estimates, which are set equal to zero, and reports statistics on them (see Section C.4). It also stores the true production and estimated production for each stock and recovery year. When all of the recovery years have been simulated, the mean relative absolute prediction errors (MAE) for the estimates of production are calculated and stored for every simulation. After all of the simulations have completed, the statistics for the MAE are placed in the output worksheets. Other outputs are calculated similarly.

Alternatives S1 and S2 report statistics of the difference in escapement due to incidental mortality (D) if enough recovery years have been simulated (at least 7). This involves keeping track of parameters and samples from 7 recovery years. Statistics summarizing the MAE for D are reported as in the production estimates. The true difference, D, is calculated using true parameters and true escapement, while the estimate of the difference, $\widehat{D}$, uses estimated parameters and estimated escapement. The methods discussed in Section D.3 explain how this is accomplished. If the number of recovery years is less than 7, the estimates of production will be carried out, but the difference in escapement due to incidental mortality will not be calculated.

This finishes the simulation, resulting in the three original data entry sheets as well as two or three more output sheets, depending on the alternatives simulated. Output files are created and can be found in the directory where the current workbook is saved (or in the program directory if the workbook is not saved).

The simple random sampling can take a long time if there are a large number of fish to sample. Therefore, some simulations may seem to have frozen, when they are actually sampling. A close watch on the progress bars will provide information on the status and speed of the simulation. A simulation can also be aborted at any time. A simulation of 2 hatchery stocks and three natural stocks took about twenty minutes to complete when simulating one recovery year and 1000 simulations on a 450mHz Pentium III machine. Be patient, as estimating the production of chinook salmon is a laborious, although necessary, process.