PACIFIC SALMON COMMISSION JOINT
CHINOOK TECHNICAL COMMITTEE

Special Report of Chinook Technical Committee HRI Workgroup on the Evaluation of Harvest rate indices for use in Monitoring Harvest Rate Changes in Chinook AABM Fisheries

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Notation for equations

Subscript	Description
a	Age
b	Base period year
f	Fishery
F	Number of Fisheries
i	Iteration
l	Legal
n	Number of stock-age combinations used in calculation of harvest rate metrics
s	Stock
sl	Sub-Legal
t	Time Period
x	Strata (Combination of time periods and/or fishery subareas)
y	Year
η	Number of data points in the fishery strata.
Notation	**Description**
AEQ	Adult equivalent factor
aeqCWT	Adult Equivalent CWT Catch
AI	Abundance Index
AIC	Akaike Information Criteria
Bias(HRI)	Bias for estimated fishery harvest rate index
BP	Base Period
bpER	Base Period Average ER
C	Catch
COH	Cohort Size
CWT	Estimated number of CWTs in landed harvest
cwtCOH	CWT Cohort Size
cwtHR	CWT harvest rate
CWTRec	Observed number of CWTs
cyERI	Current year ER index
D	Distribution of Cohort
D'	Combined distribution and proportion vulnerable parameter
Diff	Relative Difference (%) between an incomplete estimate and the associated complete estimate
dmr	Drop-Off Mortality Rate
DropOff	Dropoff (Number of fish encountered by gear but not landed)
enc	Encounters of Sub-Legal sized Fish (i.e., fish that are smaller than the minimum size limit that can be legally retained).
ER	Exploitation Rate
Esc	Escapement

HR	Harvest Rate
HRI	Harvest Rate Index
$\overline{HRI}$	Average HRI
hriScalar	HRI Scalar
HRItar	Target Harvest Rate Index
K	Proportionality Constant
$L(p \mid Y_i)$	Likelihood of parameter value p given an observation Y_i
m	Number of base period years containing CWT data
$MatRte_{s,a}$	Maturation rate by stock and age.
MatRun	Mature or Terminal Run
MSE(HRI)	Mean Squared Error of an HRI
N	Abundance
$NMR_{a,t}$	Number of fish remaining in ocean after fisheries and maturation for age a in time period t
$\overline{P_{f,x}}$	Average percent of the total abundance in fishery f and stratum *x*.
PNV	Proportion Non-Vulnerable
PR	Proportion of a cohort that can be legally retained (determined by size limit restrictions)
$Pr\ (Y_i \mid p)$	Probability of observation Y_i given parameter value *p*
PV	Proportion Vulnerable
RE	Relative Error (%) of an estimate compared to the true value
rmr	Release Mortality Rate for Sub–Legal fish
RMSE(HRI)	Root Mean Squared Error of an HRI
romERI	Ratio of Means ER Index (Type of HRI)
saERI	Simple Average ER Index (Type of HRI)
SAFT	Stock, Age, Fishery, Time period
SampleRate	Sampling rate
Shak	Sub–Legal (Shaker) mortalities
SL	Size Limit
SPFI	Stratified Proportional Fishery Index (Type of HRI)
$SurvRte_a$	Survival from age a-1 to age a
TAC	Total Allowable Catch
taeqCWT	Adult Equivalent CWT Total Mortality
TAHR	Total Annual Harvest Rate
THR	True Harvest Rate
THRI	True Harvest Rate Index
TimeDist	Distribution of TAC
Var(HRI)	Variance about estimated fishery index
σ_i	Standard Error

List of Acronyms with Definitions

Acronym	Definition
AABM	Aggregate Abundance Based Management
ADFG	Alaska Department of Fish and Game
AEQ	Adult Equivalent
AI	Abundance Index
AIC	Akaike Information Criteria
APC	Average Proportion Correction procedure
BY	Brood Year
CDFO	Canadian Department of Fisheries and Oceans
CRITFC	Columbia River Inter-Tribal Fisheries Commission
CTC	Chinook Technical Committee
CV	Coefficient of Variation
CWT	Coded Wire Tag
CY	Catch Year
ER	Exploitation Rate
ERI	Exploitation Rate Index
FP	Fishery Policy Scalar
HR	Harvest Rate
HRI	Harvest Rate Index
iid	Independent Identically Distributed
IM	Incidental Mortality
ISBM	Individual Stock Based Management
MSE	Mean Square Error
NBC	North British Columbia
NBC T	North British Columbia Troll
NMFS	National Marine Fisheries Service
NWIFC	Northwest Indian Fisheries Commission
PNV	Proportion non-vulnerable
PSC	Pacific Salmon Commission
PST	Pacific Salmon Treaty
PT	Pre Terminal
PV	Proportion vulnerable
QIN	Quinault Indian Nation
RE	Relative Error
ROM	Ratio of Means
SA	Simple Average
SAFT	Stock, Age, Fishery and Time Period

Acronym	**Definition**
SEAK	SE Alaska
SEAK T	SE Alaska Troll
SPFI	Stratified Proportional Fishery Index
TAC	Total Allowable Catch
TLA	Three Letter Acronym
VB	Visual Basic
WCVI	West Coast Vancouver Island
WCVI T	West Coast Vancouver Island Troll

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Executive Summary

During the course of renegotiations of Chapter 3 of the 1999 Agreement, several issues emerged with respect to the use of fishery harvest rate indices (*HRI*s) as measures of negotiated harvest rate reductions in AABM fisheries. In particular, the accuracy of the metric currently used for the WCVI fishery was questioned, as the observed value of the metric in recent years was much higher than expected, when considering observed landed catch (report to the bilateral PSC Commission entitled 'High Priority CTC Small Group Assignments, July 2007'). This led to questions regarding the utility of this particular metric for a fishery where significant changes in temporal harvest patterns have occurred relative to the 1979-1982 base period. Because HRIs are an integral component of the catch equations used to set allowable harvest levels, and had not been evaluated since the mid-1980s, the Commission requested that the Chinook Technical Committee (CTC) evaluate several candidate metrics for use in monitoring harvest rate changes in all three AABM fisheries.

A simulation model was written in VB.NET Express to simulate CWT tagging and recovery processes (described in Chapter 2). With the model, both true aggregate abundance and harvest were known with certainty, enabling comparison of the true harvest rate index (HRI, calculated as the ratio of the true harvest rate in a year divided by the average true harvest rate during the base period) with the values produced by each harvest rate metric.

The simulation model represented four ocean and one terminal fishery, with associated catch sampling of a stock aggregate that consisted of 16 stocks. The simulation was run over 19 years. Catch and catch sampling for ocean fisheries was divided into three periods for each year. Characteristics of three of the ocean fisheries (e.g. temporal harvest pattern, stocks encountered) were similar to those of the three AABM fisheries, i.e. SEAK, NBC and WCVI; the fourth ocean fishery was the same as the third fishery, except there was no harvest in one time period over the latter half of the simulation period. The simulation model also incorporated sampling for CWTs in ocean fisheries, a terminal fishery for each stock, and in spawning escapements.

Stock characteristics (e.g. maturation rates, cohort sizes, length at age, CWT mark rates) were similar to 16 of the 30 stocks currently included in the Pacific Salmon Commission (PSC) Chinook Model. These stocks were selected to provide a mix of spring and fall run types which had different distributions among ocean fisheries 1 through 3 (stocks were distributed identically to ocean fisheries 3 & 4).

Stochasticity was incorporated into many of the model processes in an attempt to better represent 'real world' variability in the following processes:

- Abundance of age 2 cohort sizes
- The proportion of age 2 production that is tagged with CWTs
- Distribution of stocks among preterminal fisheries by time period
- Legal-sublegal size of fish encountered
- Drop-off mortality
- Maturation rates

- CWT sampling

Structurally, the model simulated the capture, release, and CWT sampling of individual fish, separately accounted for mortalities of fish from each stock and CWT release group. In addition, variability in the size of individual fish was incorporated using estimated of means and standard deviations of length at age developed by Morishima and Chen (2006).

Two simulation scenarios were evaluated. The first maintained the same harvest rates across all years (with stochastic variation), while the second incorporated a harvest rate reduction after 5 years, to simulate reductions implemented in the 1999 Agreement. Each scenario was run 25 times (iterations), with 10 samples of CWT recoveries per iteration. The iterations were designed to provide information on process variability while the CWT samples were designed to provide information on sampling variability.

CWTs ‘recovered’ in each model run were subject to cohort analyses (Chapter 3) to calculate stock/age/fishery exploitation rates (ERs). These ERs were then used to calculate several HRI metrics: ratio of means (ROM), simple average (SA) and the stratified proportional fishery index (SPFI) for the four ocean fisheries. (Note that there was no need to evaluate HRI metrics for terminal fisheries since they were modeled using fixed harvest rates.) An investigation into a fifth alternative (gauntlet index, Appendix 1) to estimate fishery harvest rates was initiated, but was not completed due to the press of time available to complete the analysis. Although, we did not use the estimation algorithm of this alternative, we did compute the true harvest rate metric against which all indices were evaluated using this approach.

The ROM, SA, and SPFI HRI metrics were evaluated (Chapter 4) using a set of standardized criteria (described in Chapter 5). The performance of each HRI metric was evaluated for bias and precision using relative error (RE), root mean square error (RMSE), likelihood (LK) and the Akaike Information Criteria (AIC). The first three metrics compare the performance of each metric independent of their complexity. The latter adjusts the comparison to account for differences in complexity. Implications of changing HRI metrics from those used to establish AABM impact constraints under the 2008 Agreement are described in Chapter 6.

The stochasticity built into the simulation model produced considerable variability among stock/age ERs and HRIs in all fisheries. While model complexity makes it difficult to definitively explain all observed variability in the stock/age ERs and the individual stock/age HRIs that can be calculated from them, such variability was usually attributable to small cohort sizes, low tagging rates, low ERs, or a combination of these factors. The high number of age 2 CWT recoveries observed in all fisheries did not accurately reflect the lack of such recoveries in the real AABM fisheries. However, further analysis indicated that inclusion of age 2 recoveries did not bias the estimates of HRIs. The first HRI estimate for an incomplete brood year age-specific index was usually biased high, compared to subsequent estimates as the brood completed. However, this observation is similar to that observed in the real AABM fisheries, and therefore was not considered to be anomalous.

All three HRI metrics were found to be unbiased. However, based on the RE, RMSE and LK criteria, the SPFI performed the best for all fisheries and years. Even when complexity, i.e. the number of parameters, was accounted for (AIC), the SPFI performed the best for most years in most fisheries. When CWT recovery data from stocks not included in the base period are included in the SPFI calculation (something that cannot be done for most of the other metrics), the SPFI performs even better. Thus, the metric that allows stratification in its estimation provides the best estimate of harvest rate changes among the three HRI metrics examined.

Considering the changes in temporal patterns of the WCVI AABM fishery over the years, and the impact this may have on estimates of harvest rate changes, it is recommended that the SPFI be adopted for use in the WCVI AABM fishery. While doing so for the NBC fishery probably would not significantly improve estimates of harvest rate changes in this fishery, as there is no feasible stratification other than a complete year and area-wide stratum due to inadequate catches in certain times and areas, it may be desirable to do so for the sake of consistency among the three AABM fisheries. In order to inform a policy decision on adopting a new HRI metric, additional PSC Chinook Model calibration activities, described in Section 6, are needed to maintain the currently negotiated relationships between catch and abundance.

Chapter 1. Introduction

Fishery Harvest Rate Indices (HRIs) are employed by the Chinook Technical Committee (CTC) to reflect relative changes in fishery harvest rates. HRIs measure changes in harvest rate relative to a selected base period. They can be calculated for individual stock-ages, or aggregated across stocks and ages for one or more fisheries. Because individual stock and age HRIs will vary among stocks in a fishery aggregate, the CTC calculates an aggregate HRI that is meant to measure the average across-stock-age harvest rate reductions in a fishery. Note that because harvest rate reductions are tied to base period exploitation rates (ERs), only those coded wire tagged (CWT) stocks present during the base period can be included in the HRIs as currently calculated for the AABM troll fisheries.

HRIs can be calculated by several methods (TCCHINOOK 1988). Currently the CTC uses the 'ratio of means' method (ROM) to monitor the reduction in harvest rate in the West Coast Vancouver Island (WCVI) and Northern British Columbia (NBC) troll fisheries. This metric is calculated as the sum of current year ERs divided by the sum of the corresponding base period average ERs for those stocks and ages intercepted in each troll fishery. Another HRI metric that can be used is the stratified proportional fishery index (SPFI), which has been used to measure harvest rates in the Southeast Alaska (SEAK) troll fishery. In the late 1980's, the CTC developed the 'ratio of means' metric (ROM) as the best HRI under stable fishing patterns. During the mid 1990's a SPFI was developed as a statistic to represent relative changes in annual fishery harvest rates under unstable spatial and temporal fishing patterns.

Historical relationships between HRIs, abundance, and catches were employed to quantify the allowable catches levels under the 1999 and 2008 Agreements and are reported by the CTC to provide post-season information on relative changes in fishery harvest rates. SPFIs were used in the development of the Aggregate Abundance Based management (AABM) fishing regime for SEAK for the 1999 Agreement. For the NBC and WCVI AABM fishery complexes, however, the ROM HRI was employed because fishing patterns were relatively stable (the vast majority of the annual harvest occurred during the summer months). However, the fishing pattern for the WCVI troll fishery has shifted to the late fall and spring with minimal catches during the summer.

The PSC Chinook Model does not include all stocks so proportionality constants are used to convert actual catch to model catch. There is some indication that the proportionality constants for all three AABM fisheries have been deviating from their pre-1999 averages. As these constants are also a function of HRIs, any connection between changes in the proportionality constants and the anomalies observed with some of the HRIs should be investigated. Work examining the relationship between HRIs and proportionality constants is reported in the Appendix to Assignment 2 of the report of the CTC Support Group on High Priority Assignments (2007). Alternative HRI metrics behave differently, as illustrated for the WCVI troll fishery. An analysis to determine which HRI metric is most robust to variability in data availability and fishing patterns was undertaken as a result of the CTC Support Group's report at the instruction of the PSC negotiators. This report presents the results of the work conducted by the CTC Support Group in response to the negotiators' high priority assignment to evaluate alternative metrics to measure HRIs and recommend the metric that most accurately reflects true fishery harvest rates.

The CTC Support Group developed a computer simulation model to generate datasets that could be used to evaluate the performance of alternative HRIs against known true values (Chapter 2). Cohort analyses were performed on each dataset to provide estimates of ERs for computing HRI metrics (Chapter 3). Three HRIs were evaluated: a Simple Average, ROM, and SPFI (Chapter 4). Performance was evaluated using standardized criteria (described in Chapter 5). Implications of changing HRIs from those used to establish AABM impact constraints under the 2008 Agreement are described in Chapter 6. An investigation into a fifth alternative metric to estimate fishery harvest rates was initiated, but was not completed (Appendix 1). Appendix 2 contains file names and directories on the PSC FTP site where computer program code and executables, input files, and brief instructions for using the various programs employed to complete this analysis are available.

Chapter 2. Fishery Harvest Rate Model

The performance of alternative HRI metrics can best be evaluated by comparing estimated with true values. An HRI simulation model, written in Visual Basic Express 2008 (VB.Net), was developed to generate catch and CWT recovery data for evaluation of alternative HRI metrics. A description of the model is provided in Appendix 3.

The simulation model represents ocean and terminal fishing and catch sampling of hatchery and wild Chinook stocks. Statistics on the true catch and incidental mortalities by fishery, stock and age, and escapement by stock and age are produced. Model processes for a Chinook stock include distribution, growth, maturation, and natural mortality (Figure 2-1). Model processes for a fishery include catch limits (quotas) or harvest rate controls, incidental mortality and drop-off mortality. Sampling processes include simulation of CWT recovery programs for catch and escapement.

A model year begins October 1 and is divided into three time periods of unequal length. The time periods are October through April, May and June, and July through September. A mixture of 16 spring and fall type stocks is represented in the model (Table 2-1). The simulation model was configured to simulate four preterminal AABM fisheries and one terminal fishery. Two of the AABM fisheries (fishery numbers 3 and 4) were modeled with identical initial stock compositions and annual harvest levels, but with different distribution of catch among time periods to permit evaluation of the effects of changes in fishing patterns on HRI performance; specifically, fishery 4 was closed during one of the time periods for some years.

During each time period, preterminal fisheries are simulated as quotas so that the model continues simulating encounters of fish until the catch of legal sized fish allocated to that time period equals the quota. Fishing processes are simulated on an individual fish basis, using stochastic processes to simulate the effects of variability on the following processes:

- Abundance of age 2 cohort sizes.
- The proportion of age 2 production that is tagged with CWTs.
- Distribution of stocks among preterminal fisheries.
- Legal-sublegal size of fish encountered.
- Drop-off mortality.
- Maturation rates.
- CWT sampling.

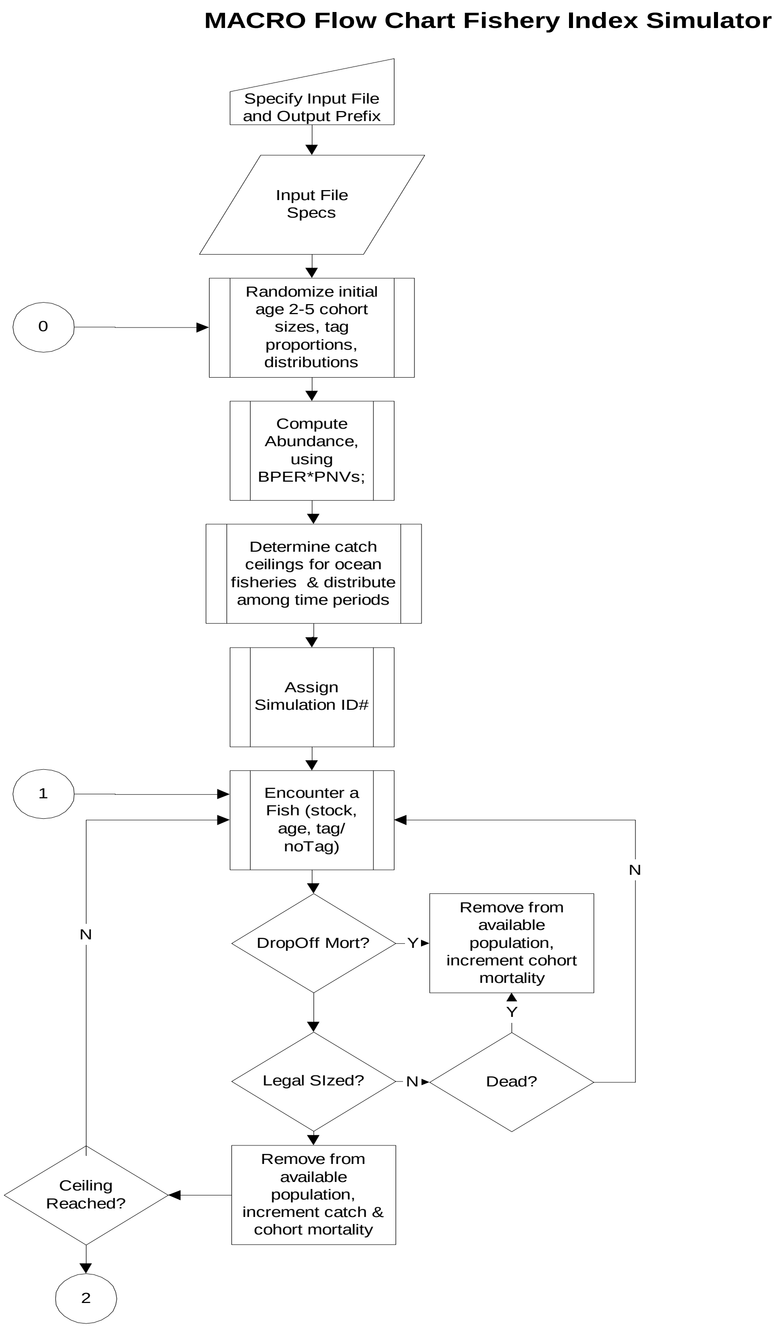


Figure 2-1. Flow chart for simulation model.

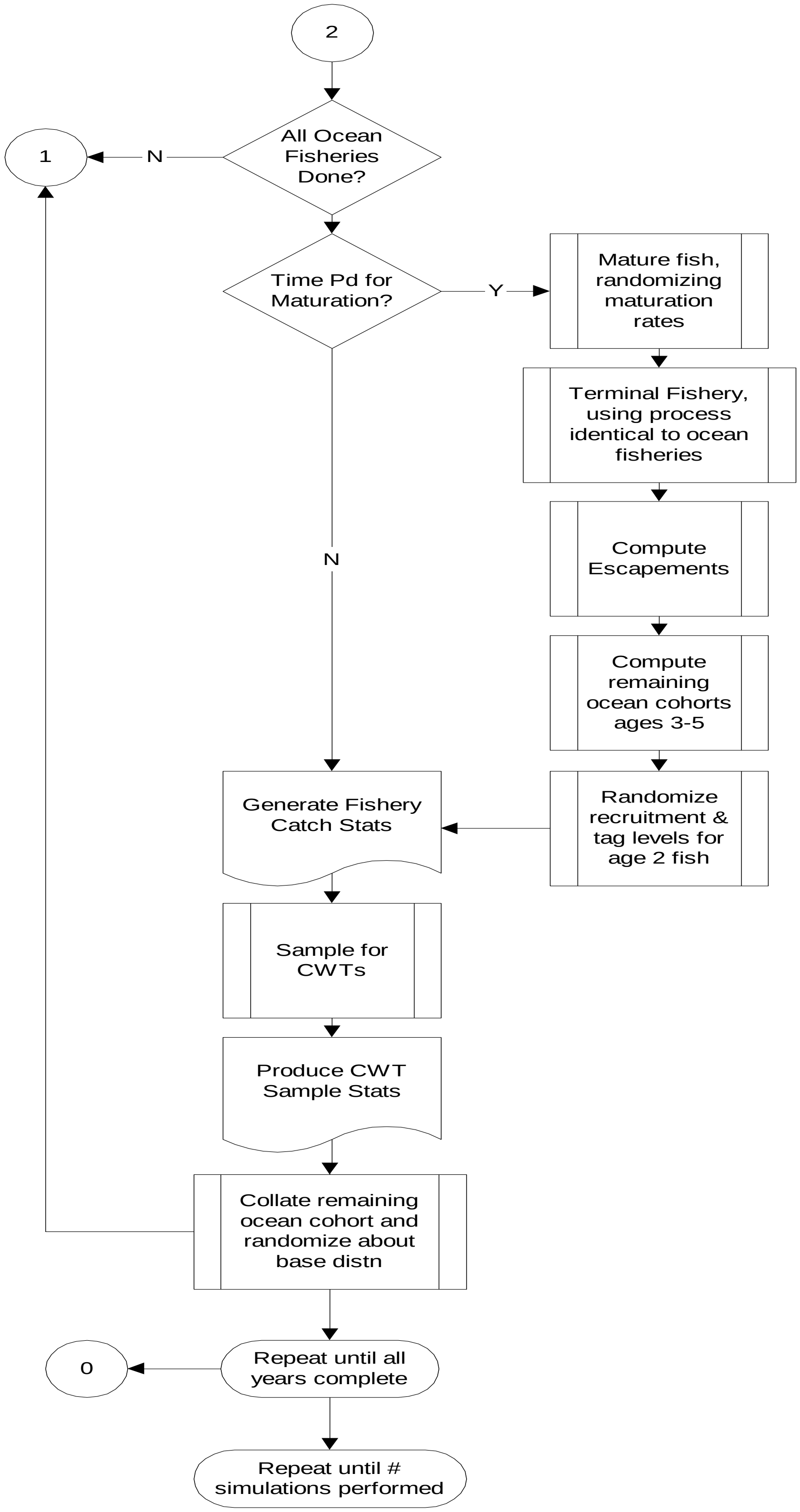


Figure 2-1 continued. Flow Chart for Simulation Model.

Table 2-1. Characteristics of the stocks used in the simulations. Stock acronyms indicate the PSC Chinook model stocks that served as basis for simulated stocks.

Stock Number	Stock Acronym	Life History	Stock Type	Tags available in BP
1	Alaska	spring	hatchery	Y
2	FRE	spring	wild	N
3	FRL	fall	hatchery	N
4	RBH	fall	hatchery	Y
5	RBT	fall	wild	N
6	GSQ	fall	hatchery	Y
7	NKF	fall	hatchery	Y
8	PSF	fall	hatchery	Y
9	SKG	fall	hatchery	N
10	WCH	fall	hatchery	Y
11	URB	fall	hatchery	Y
12	SPR	fall	hatchery	Y
13	CWF	fall	hatchery	Y
14	WSH	spring	hatchery	Y
15	ORC	fall	hatchery	Y
16	WCN	fall	hatchery	Y

A fish is randomly encountered (hooked) by the gear. If the fish does not drop off, and is of legal size, it is landed, added to the total catch of the fishery, and subtracted from the available cohort. If it drops off, or is below the legal size limit, it is subject to incidental mortality. If it dies from incidental mortality, it is subtracted from the available cohort. If the encountered fish does not die, it remains in the available cohort and is immediately available for another encounter (no sulk time) (Figure 2-2). This fishing process continues until the quota for that time/area is achieved. After preterminal fishing, maturation, natural mortality, and recruitment occur, depending on stock type (spring or fall).

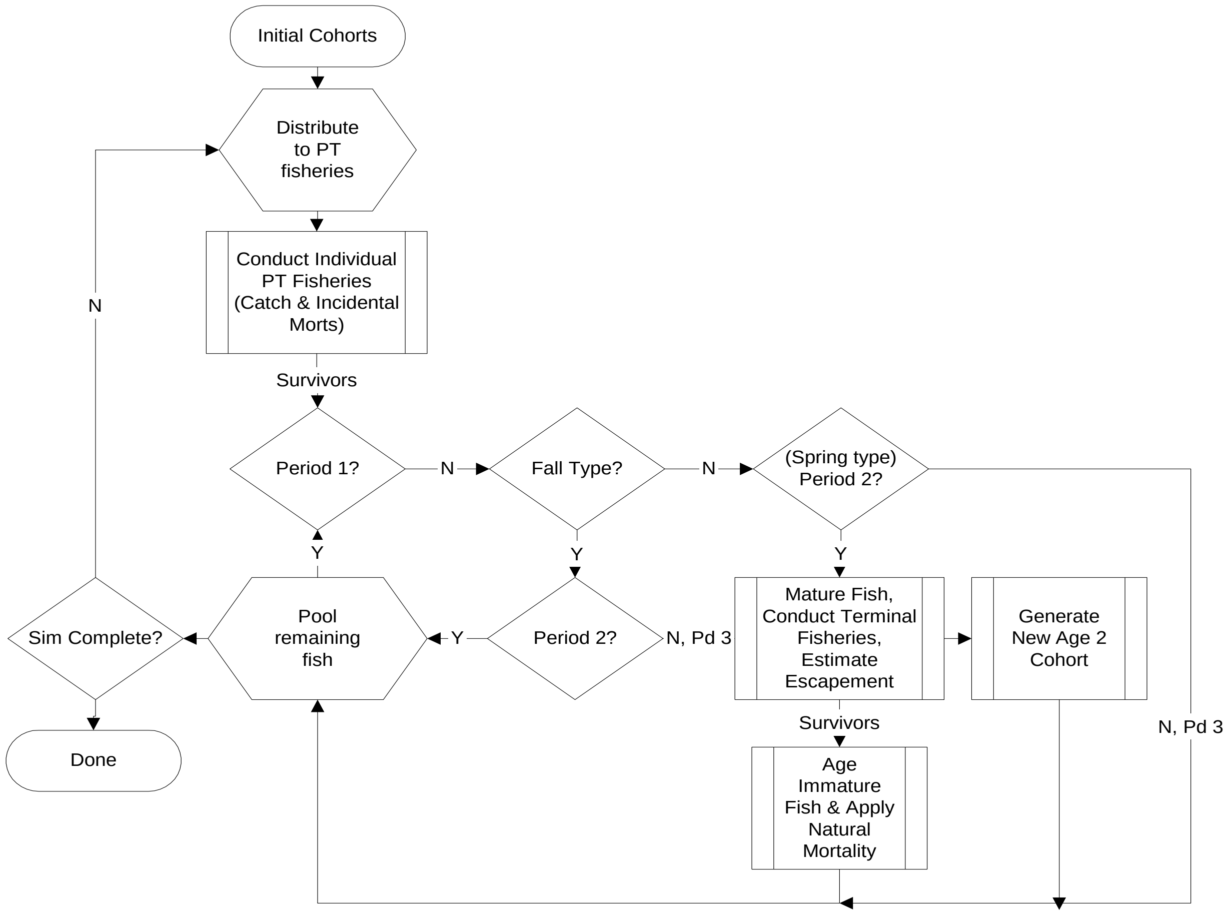


Figure 2-2. Annual cycle in simulation model.

The simulation model was not intended to mimic specific fisheries or stocks represented in the PSC Chinook model. Fisheries represent a range of ocean fisheries from north to south as well as include a representative terminal fishery. Stocks were chosen to represent a range of life histories, run types, and distribution patterns.

2.1.1 Scenario description

Two scenarios were designed to model a single transition from an “Old” to a “New” fishing pattern in the four ocean fisheries beginning in 1984 to mimic changes in the proportion of the annual catch taken by time period. The second scenario was designed to evaluate performance of alternative HRI metrics when fishery harvest rates are substantially reduced. In the second scenario, HRIs were reduced by 30% for fisheries 1 and 2 and for fisheries 3 and 4 by 70% from 1984, compared to scenario 1.

A terminal fishery (Fishery 5) is included as a representative of terminal fisheries with a fixed harvest rate and with sampling for tags in both scenarios. It is not necessary to compute HRI metrics for the terminal fishery, because it was simulated using fixed harvest rates.

The four preterminal fisheries were simulated to mimic AABM fisheries. An abundance index is generated and a harvest rate scalar is applied to stock-age specific base period exploitation rates. Breakpoints, minimum abundance triggers, and harvest rate scalars[1] are summarized in Table 2-2.

Table 2-2 Breakpoints, HRIs and minimum abundance triggers used in two model scenarios.

Fishery	Breakpoint	Minimum Abundance Trigger	HRI Scalars Scenario 1	HRI Scalar Scenario 2 after 1983
1		0	6.250	4.375
1	1	113,085	7.500	5.250
1	2	118,660	8.000	6.125
2		0	5.000	3.500
2	1	60,300	6.250	4.375
2	2	66,185	7.500	5.250
3		0	1.500	0.450
3	1	88,835	3.000	0.900
3	2	101,500	4.500	1.350
4		0	1.500	0.450
4	1	88,835	3.000	0.900
4	2	101,500	4.500	1.350

By default, the simulation model starts each run in 1979 and runs for 19 years. Alternative HRIs were evaluated using 25 iterations of the two scenarios, with fisheries and escapements sampled for CWTs 10 times per iteration. Iterations provide information on variability due to process error while multiple sampling events for CWTs provide information on variability due to sampling error.

Because of the time required to perform the Monte Carlo simulations, the sheer volume of data produced by the model, and the effort required to generate estimates of alternative HRIs, data for only six years were used in the analysis. Catch years 1982 and 1983 were selected to provide data for the first two brood years that would complete their life cycles under the "Old" fishing pattern. Catch years 1991 and 1992 were selected to provide data for the first two brood years that would complete their life cycles under the "New" fishing pattern. Catch years 1985 and 1986 were selected to provide data for brood years that would be affected during the transition from the "Old" to "New" fishing patterns.

2.1.2 Output descriptions

Each run of the simulation model produces several datasets (see Appendix 3 for detailed descriptions):

[1]Inherent in the approach to Abundance based management used by the PSC, key abundances are related to harvest rates that were negotiated by the parties. These abundances at which harvest rates change in the relationship are called breakpoints, and the associated harvest rate scalars that were used at these points are shown Table 2.2. (below).

- cohort sizes and the number of tagged and untagged fish in catches and CWT samples by stock and age. Cohort analysis (Chapter 3) is performed for each CWT sample to estimate tagged cohort sizes and ERs;
- annual maturation rates; and
- true numbers of tagged and untagged fish in catches and escapements. Data in this file are used to generate estimates of true exploitation and fishery harvest rates for comparison with alternative HRI metrics.

Chapter 3. Cohort Analysis

This section documents the methods incorporated into a FORTRAN 90 program developed to generate stock, age, fishery and time period (SAFT) estimates of ERs for both complete and incomplete broods. The program generates estimates of SAFT ERs for both complete and incomplete broods, as well as cohort sizes, maturation rates, AEQs and PNVs. The section describes input data files and output formats for cohort analysis results to be used to estimate alternative HRI metrics. The main input data file for the cohort analysis program is *runIDCATCHSAMPLES.CSV* (renamed to *CATCHSAMPLES.CSV)* which is output by the HRI simulation program (described in Chapter 2) and contains the simulated samples of tagged fish for each simulation and for multiple samples taken per simulation. The catch sample file identifies the catch year, time period, fishery and stock and the sample rate used for each time period and fishery. The input file, *MATRATES.SIM*, containing the maturation rates by catch year and stock and iteration is generated as output from the HRI simulation program with the name *runIDMaturationRates.CSV*.

3.1 Why both complete and incomplete broods?

In order to generate more timely estimates of fishery HRIs, the methods employed by the CTC for cohort analysis generate estimates of SAFT ERs before all the CWT data for the brood years are completely available. For any given catch year, four estimates of SAFT ERs will be made for age 2 fish, three estimates for age 3 fish, two for age 4 fish, and one for age 5 fish. Only the final estimate is based on a complete set of tag data. So for any given catch year, a set of estimates of the SAFT ERs based on complete tag data for all ages do not become available until the third year after the catch year. For instance a set of metrics based on complete data for all ages encountered in fisheries in 1980 would not be final until 1983, and for age 2 fish four possible estimates of ERs can be generated (Table 3-1). In practice these estimates stabilize when the second year of CWT data is available (see section 3.5).

Table 3-1. Estimates of ERs for a calendar year with incomplete and complete estimates as CWT data for all ages in the brood years encountered become available. Table shows example for ERs for ages encountered in catch year 1980.

Year of Estimate of 1980 metric	Age 2	Age 3	Age 4	Age 5
1980 estimate in year of fishery	*1978 BY Incomplete 1*	*1977 BY Incomplete 1*	*1976 BY Incomplete 1*	***1975 BY Complete***
1981 estimate	1978 BY Incomplete 2	1977 BY Incomplete 2	**1976 BY Complete**	
1982 estimate	1978 BY Incomplete 3	**1977 BY Complete 3**		
1983 estimate	**1978 BY Complete 4**			

3.2 Cohort Reconstruction

Cohort analysis methods reconstruct a cohort using escapement CWT data for the oldest available age as the starting point. Terminal fishery mortalities are added to the escapement to estimate the terminal run size. Ocean fishery mortalities are then added to the terminal run size to estimate abundance prior to ocean fishing. Then natural mortality is added to estimate the ocean abundance after fishing for the next youngest age class.

The terminal run (mature run) is calculated for each age as the escapement plus the mortalities in the terminal fishery (fishery 5 in the simulation). In the Simulation model, maturation and escapement only occur in one time period, depending on run type. (***t*** = 3 for fall stocks; ***t*** = 2 for spring stocks; note that for purposes of the equations, time periods corresponding to a fall stock are used). Starting with the last time period ***t*** for a given stock the mature run is:

$$MatRun_{a,t} = Esc_{a,t} + \sum_{f=term}(CWT_{a,f,t} + Shak_{a,f,t} + DropOff_{a,f,t}) \qquad (3\text{-}1)$$

The mature run only represents the fish observed in the terminal area. The ocean cohort size prior to fishing in the last time period ***t*** includes the mature run, the mortalities in fisheries and the fish remaining after fisheries and maturation:

$$cwtCOH_{a,t} = MatRun_{a,t} + NMR_{a,t} + \sum_{f=\mathrm{Pre}Term}(CWT_{a,f,t} + Shak_{a,f,t} + DropOff_{a,f,t}) \qquad (3\text{-}2)$$

The number of fish remaining after preterminal fisheries and further reduced by mature fish escaping to terminal areas, constitutes the cohort for the next time period or age. If the time period is the last for the age, then survival to the next age must be accounted for:

$$NMR_{a,t} = \frac{cwtCOH_{a+1,1}}{SurvRte_{a+1}} \qquad (3\text{-}3)$$

Otherwise the number remaining in the ocean after fisheries represents the cohort for the next time period or age, or:

$$NMR_{a,t} = cwtCOH_{a,t+1} \qquad (3\text{-}4)$$

For incomplete brood years, the remaining cohort size for the last time period of the oldest age with CWTs available is estimated as:

$$NMR_{a,t} = \frac{MatRun_{a,t}(1 - MatRte_{a,t})}{MatRte_{a,t}} \qquad (3\text{-}5)$$

The cohort size for time periods with no maturation is computed by adding estimates of fishery mortality to the fish remaining after fisheries:

$$cwtCOH_{a,t-1} = NMR_{a,t} + \sum_{f \in preterm} (CWT_{a,f,t-1} + Shak_{a,f,t-1} + DropOff_{a,f,t-1}) \qquad (3\text{-}6)$$

Note that for the oldest age the number remaining after maturation in the last time period will be zero.

The SAFT ERs for ocean fisheries in time period ***t*** are:

$$ER_{a,f,t} = \frac{CWT_{a,f,t}}{cwtCOH_{a,t}} \qquad (3\text{-}7)$$

Some of the fishery HRIs under consideration require SAFT ERs to be expressed in terms of adult equivalents. Adult equivalents are the anticipated number of fish that would be expected to mature in the current or any future year, or:

$$AEQ_a = MatRte_a + \sum_{A=a+1}^{MaxAge} \left[MatRte_A * \prod_{B=a+1}^{A} SurvRte_B * \prod_{C=a}^{A-1} (1 - MatRte_C) \right] \qquad (3\text{-}8)$$

3.2.1 Maturation Rates

For estimates with incomplete CWT data (see equation 3-5) the *MatRte* used are the average stock-age maturation rates output in the file *runIDMATRATES.CSV*. Once tag data from older ages become available the maturation rate can be calculated from the cohort analysis using:

$$MatRte_{a,t} = \frac{MatRun_{a,t}}{MatRun_{a,t} + NMR_{a,t}} \qquad (3\text{-}9)$$

3.2.2 Calculation of incidental mortalities

For each stock, fishery and age, the estimated number of CWTs is calculated by dividing the observed recoveries by the sample rate provided in the record. The estimate of encounters and shaker and drop-off mortalities are calculated using the method outlined in CTC-AWG Technical Note (2003).

The simulation model does not include non-retention fisheries; therefore consideration of incidental mortalities for legal sized fish is limited to drop off. Drop off mortalities of legal sized fish are estimated as:

$$DropOff_{a,f,t} = CWT_{a,f,t} * dmr_f \qquad (3\text{-}10)$$

and the mortalities of sublegal sized fish (shakers) are estimated as:

$$enc_{a,f,t} = \frac{CWT_{a,f,t} * PNV_{a,f,t}}{PR_{a,f,t}} \tag{3-11}$$

$$Shak_{a,f,t} = (rmr_{sl,f} + dmr_f) * enc_{a,f,t} \tag{3-12}$$

3.2.3 Proportion not vulnerable

The PNV (proportion not vulnerable) is calculated using the mean length and standard deviations provided by stock, age and time period (from file *LENGTHATAGE.SIM*) using the algorithm:

$$PNV = \frac{1}{1 + e^{-1.7(\frac{SL-\mu}{\sigma})}} \tag{3-13}$$

where SL is the fishery-specific size limit and μ and σ are the mean and standard deviation for the stock, age and time period, and 1.7 is the regression coefficient. Means and standard deviations for length at age and four annual time periods for individual stock groups were estimated from CWT recovery data by Morishima & Chen (2006) for a previously completed Chinook LOA project. For purposes of reconstructing cohorts for this project, the Morishima & Chen estimates for time periods 2, 3 and 4 were used.

3.2.4 Spring and fall stock maturation and ages.

During the cohort analysis, different time periods are used for fall and spring stocks because maturation and aging occur at different times. Table 3-2 shows an example for brood years of spring and fall stocks caught in 1981. For the spring stock the first period for each age is in the third period of 1981. So the cohort analysis carried out for spring stocks starts with time period 2 and must cross into time period 3 of the previous catch year to complete the age. For fall stocks the biological and catch year are identical and all the data for each age is available in one catch year. For the spring stocks the biological year encompasses portions of two catch years, and for each age data from two catch years are required for all fish of each age to be represented in samples. So in Table 3-2 the spring stocks caught in the third time period of 1982 represent different broods from the ones caught in time periods 1 and 2 and data from 1983 are required to have full data for each age. Therefore, while a complete cohort analysis can be carried out with four catch years of data for fall stocks, five catch years are required for spring stocks.

Table 3-2. Example showing distribution of ages over time periods for fall and spring stocks where fall stocks mature in time period 3 and age in time period 1, while spring stocks mature in time period 2 and age in time period 3. Example shown is for broods caught in 1982.

Catch Year	Time Period Number	**Age for fall stock**				**Age for spring stock**				
		Brood Year				**Brood Year**				
		1980	**1979**	**1978**	**1977**	**1980**	**1979**	**1978**	**1977**	**1976**
1981	3						**2**	**3**	**4**	**5**
1982	**1**	**2**	**3**	**4**	**5**		**2**	**3**	**4**	**5**
	2	**2**	**3**	**4**	**5**		***2***	***3***	***4***	***5***
	3	***2***	***3***	***4***	***5***	2	3	4	5	

3.3 *Input data*

The CWT recoveries are generated by the simulation model and output in the file *simidCATCHSAMPLES.CSV* (see Appendix 3 for detailed description), which provides the input of CWT data for the cohort analysis. The inputs in the last four columns are of observed tags in samples in fisheries 1-5 and in escapement (fishery=6). Before starting the cohort analysis the number of CWT fish is estimated by:

$$CWT_{a,f,t} = \frac{CWT\ \mathrm{Re}c_{a,f,t}}{SampleRate_{f,t}} \tag{3-14}$$

and for escapement where the fishery is number 6:

$$Esc_{a,,t} = \frac{CWT\ \mathrm{Re}c_{a,6,t}}{SampleRate_{6,t}} \tag{3-15}$$

The maturation rates generated by the simulation model and output as *simidMATRATES.SIM*, are used as initial maturations rates (equation 3-5) and the file *LENGTHATAGE.SIM* provides the length information by stock, age and time period which is used to estimate the PNV (equation 3-13).

3.4 *Output from cohort analysis*

The simulation model currently employs a single transition from an “Old” to a “New” fishing pattern over a 19 year period, with the first six years having the old fishing pattern. Therefore some broods will be subject only to the old pattern, some to both and some to only the new pattern. Because of computational considerations, evaluation of alternative fishery HRIs were generated for three sets of two years each, or for catch years 1982 and 1983, 1985 and 1986, 1991 and 1992 (Table 3-3). So there were two years where the ages caught were only subject to the old fishing pattern (1982 and 1983), two that were only subject to the new fishing pattern (1991 and 1992) and two years where the ages caught were from broods that were subject to both fishing patterns (1985 and 1986).

Selected data elements are output in a file format designed to expedite computation of fishery HRIs with a single file output for each iteration, CWT sample and fishery with estimates for observed and estimated tags, ERs and cohort sizes. Each iteration, sample and fishery was output to a separate file, with the file name *runidSIMnoSAMnoFISHno.CSV* where SIM is the iteration number within the run, SAM the sample number within the iteration and FISH the fishery number. Detailed results of the cohort analyses performed using data for both complete and incomplete broods are output in file *MONSTER.CSV*, where observed and estimated tagged fish, estimated incidental mortalities, ERs, terminal run, cohort sizes and maturation rates are output for all iterations, samples and catch years. The cohort analysis program generates estimates of AEQs and maturation rates in file *MATRATESAEQ.CSV* and PNVs in file *PNV.CSV*. Output files are described in detail in Appendix 4.

Table 3-3. Pattern of fishing used in the simulation model. The letter following the age indicates the brood, so for example 2A or age 2 from brood A is caught in 1979, while age 3 from the same brood is caught in 1980 (3A). The broods that are in italics have been subjected to the old fishing pattern in at least one age. The catch years in bold font are those output for further use in computation of fishery HRIs.

	Catch Year	**Age**			
		2	**3**	**4**	**5**
Old Fishing Pattern	1979	2A	3	4	5
	1980	2B	3A	4	5
	1981	2C	3B	4A	5
	1982	***2D***	***3C***	***4B***	***5A***
	1983	***2E***	***3D***	***4C***	***5B***
New Fishing Pattern	1984	2F	*3E*	*4D*	*5C*
	1985	**2G**	**3F**	***4E***	***5D***
	1986	**2H**	**3G**	**4F**	***5E***
	1987	2I	*3H*	*4G*	*5F*
	1988	2J	3I	*4H*	*5G*
	1989	2K	3J	4I	*5H*
	1990	2L	3K	4J	5I
	1991	**2M**	**3L**	**4K**	**5J**
	1992	**2N**	**3M**	**4L**	**5K**
	1993	2O	*3N*	*4M*	*5L*
	1994	2P	3O	*4N*	*5M*
	1995	2Q	3P	4O	*5N*
	1996	2R	3Q	4P	5O
	1997	2S	3R	4Q	5P

3.5 Uncertainty in estimates of ERs

The simulation was carried out for 25 iterations with 16 stocks and 10 samples of tagged fish taken in each iteration. The initial cohort size for the CWT population at age 2 averaged over iterations ranged from 2,600 for stocks 9 and 10 to 77,000 for stock 12 (Figure 3-2). The number of tags observed in a fishery sample (Figure 3-2) ranged from zero to about 1,100, with consistently low tag recoveries for stocks 9 and 10 and stock 12 having the highest number sampled. The ERs (tags over cohort size for age and period), averaged over iterations, and ranged from about from 0% to 25% in a period with the lowest ERs in stock 7 and the highest in stock 1 (Figure 3-3). In general, the ERs increase from time period 1 to 3.

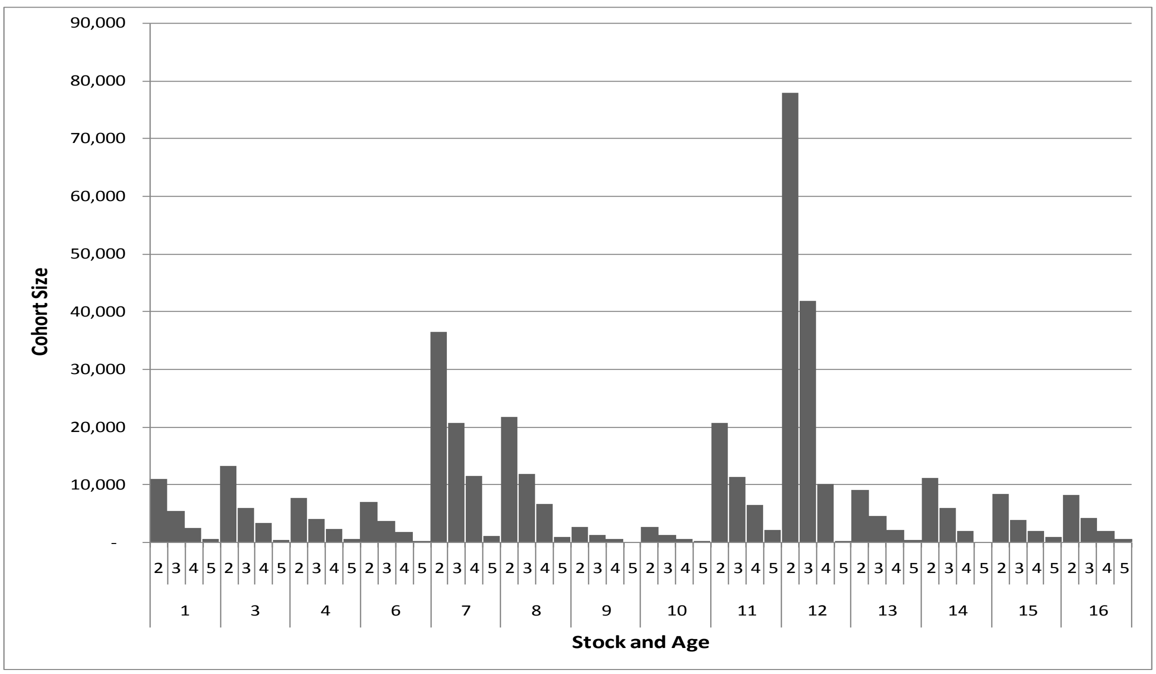


Figure 3-1. Estimated cohort size by age for time period 1 averaged over all iterations and samples for Run 4-14.

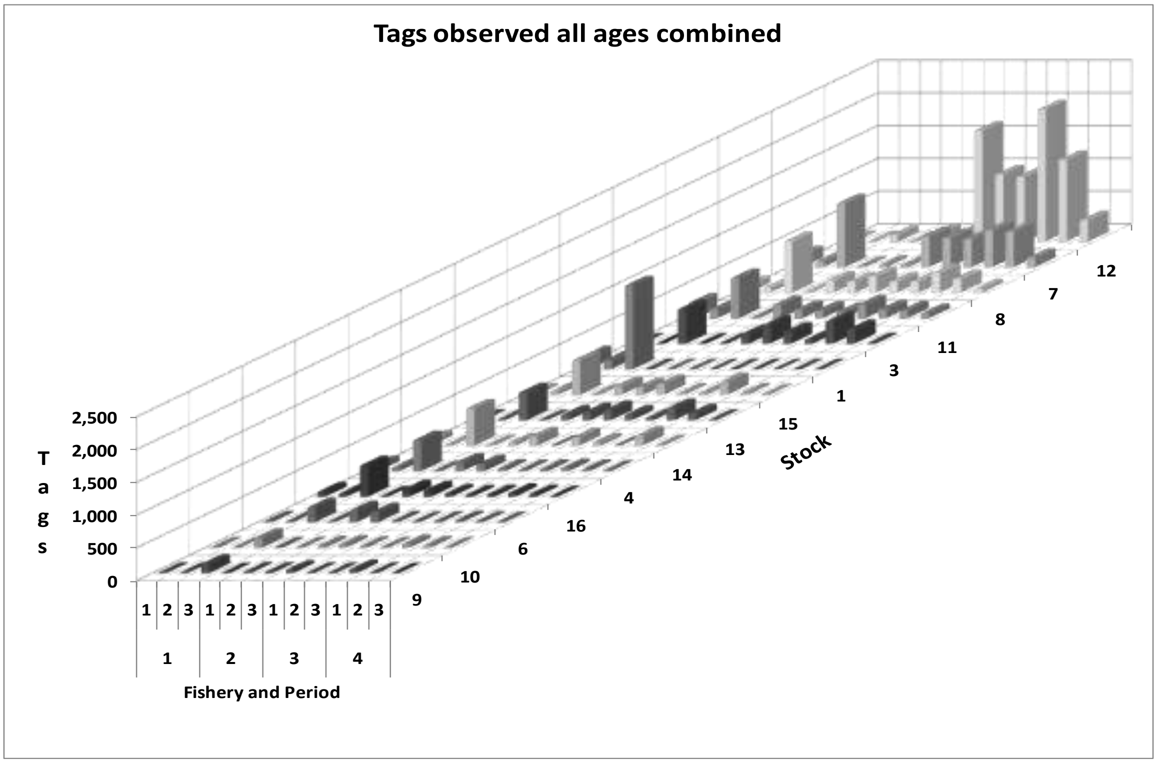


Figure 3-2. Observed tags by fishery and period for stocks ordered from stock with smallest number of tags (stock 9) to stock with largest (stock 12). All ages are combined and the number of tags is averaged over all iterations, catch years and samples for Run 4-14.

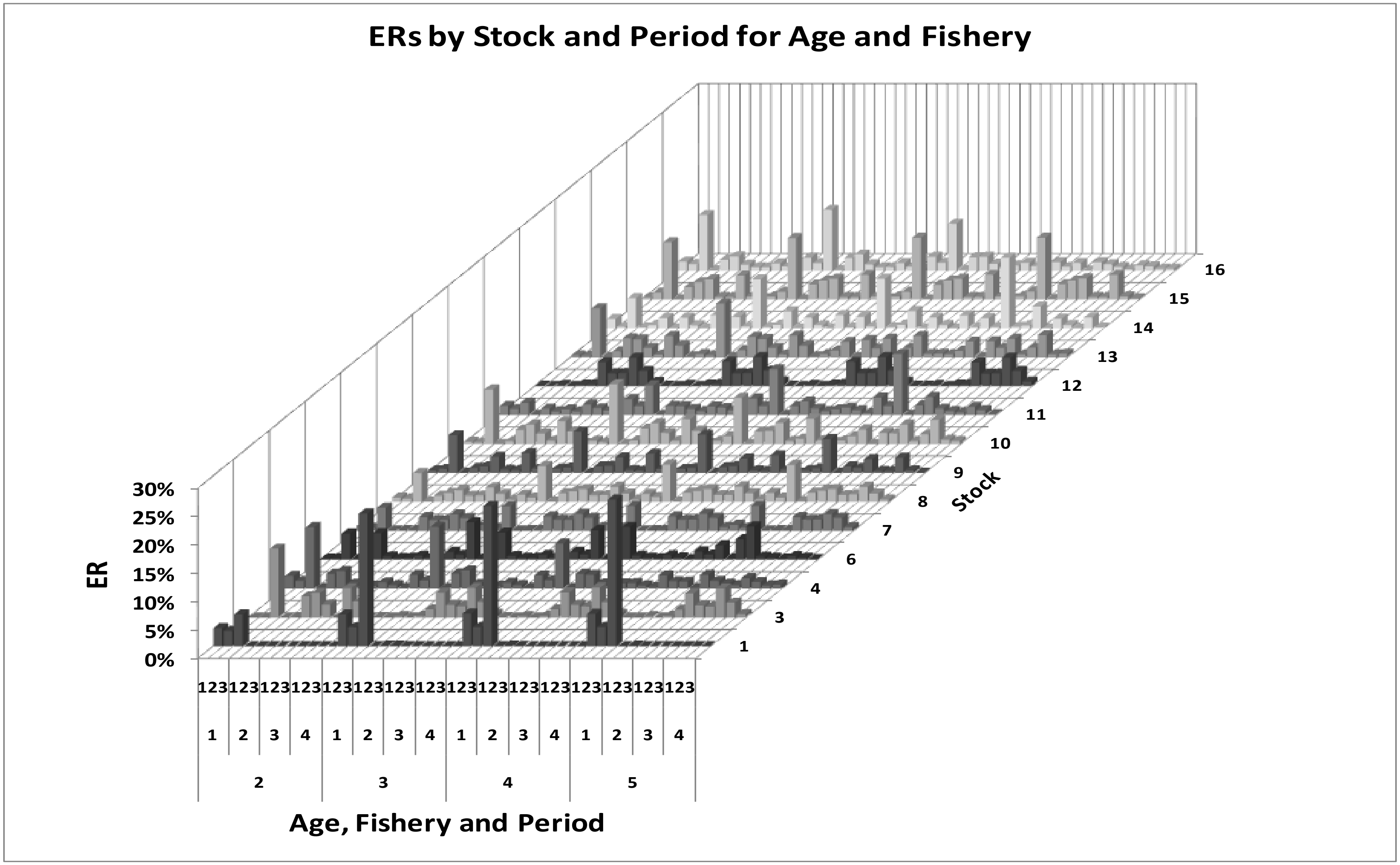


Figure 3-3. Estimated ER by age, fishery and period by stock averaged over all iterations, catch years and samples for Run 4-14.

3.5.1 Variability among iterations and among samples

Two types of errors are introduced into the estimation of ERs, process and sampling error. Each scenario is iterated 25 times and the variability in the true values among the iterations represents the process error, which can be measured by the CV among iterations [2](Figure 3-4). For the ERs simulated, age 5 has the largest process error which is due to a smallest number of fish exploited at age 5 (Figure 3-4).

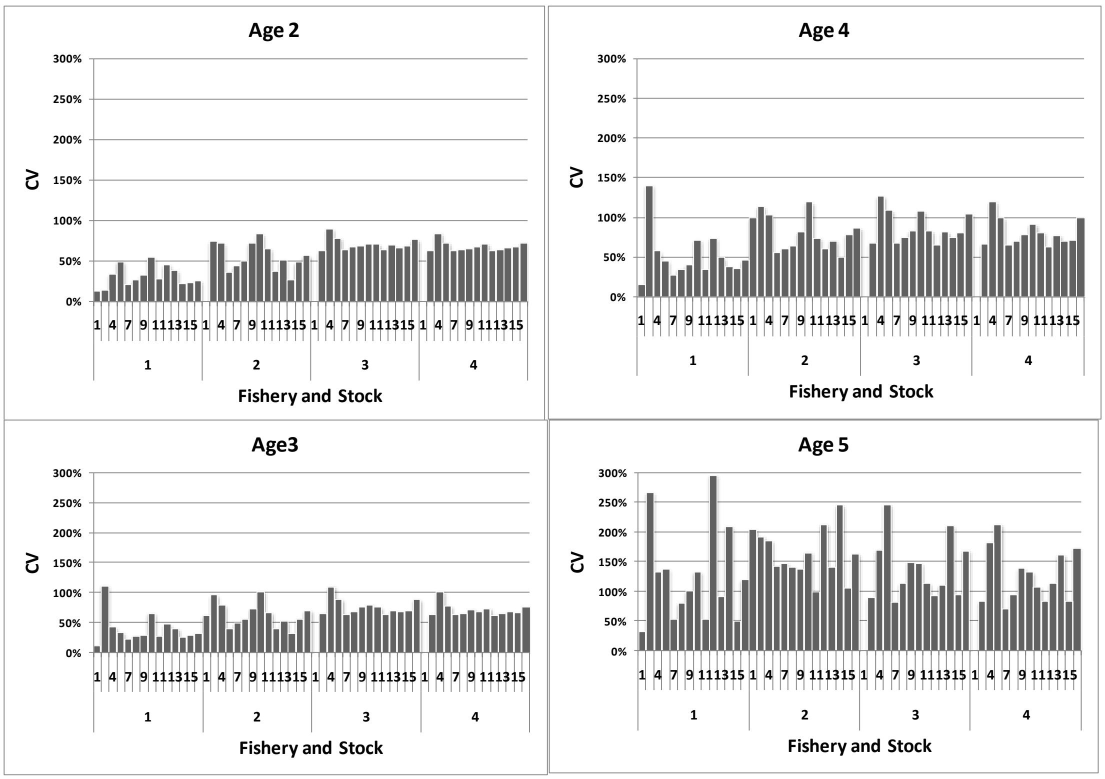


Figure 3-4 Variability among iterations for simulated ERs measured as coefficient of variation among iterations for each year shown by fishery and stock for age, averaged over years and periods.

The catches generated are sampled 10 times for CWTs and the variance among the sample estimates of catch, cohort size and ERs, within each iteration, represents the sampling error. This is measured as the CV among samples[3] . This sampling error is shown in Figure 3-5 averaged over all iterations, fisheries and time periods for each stock and year of estimate. For age 2 there are three incomplete estimates before all data necessary for a complete estimate are available, whereas for age 5 a complete estimate is available in the first year these fish are recovered. For age 2 estimates the CV among samples is higher for the catch year (CY) estimate for stocks 1 and 9, but otherwise there is little difference among the estimates (Figure 3-5). For ages 3 and 4 there is little difference between the estimates in the estimated CV among samples.

[2] CV among iteration values =(SD among iterations)/True value of ER averaged over iterations;
[3] CV among sample estimates within an iteration =(SD among samples)/Estimate of ER averaged over samples;

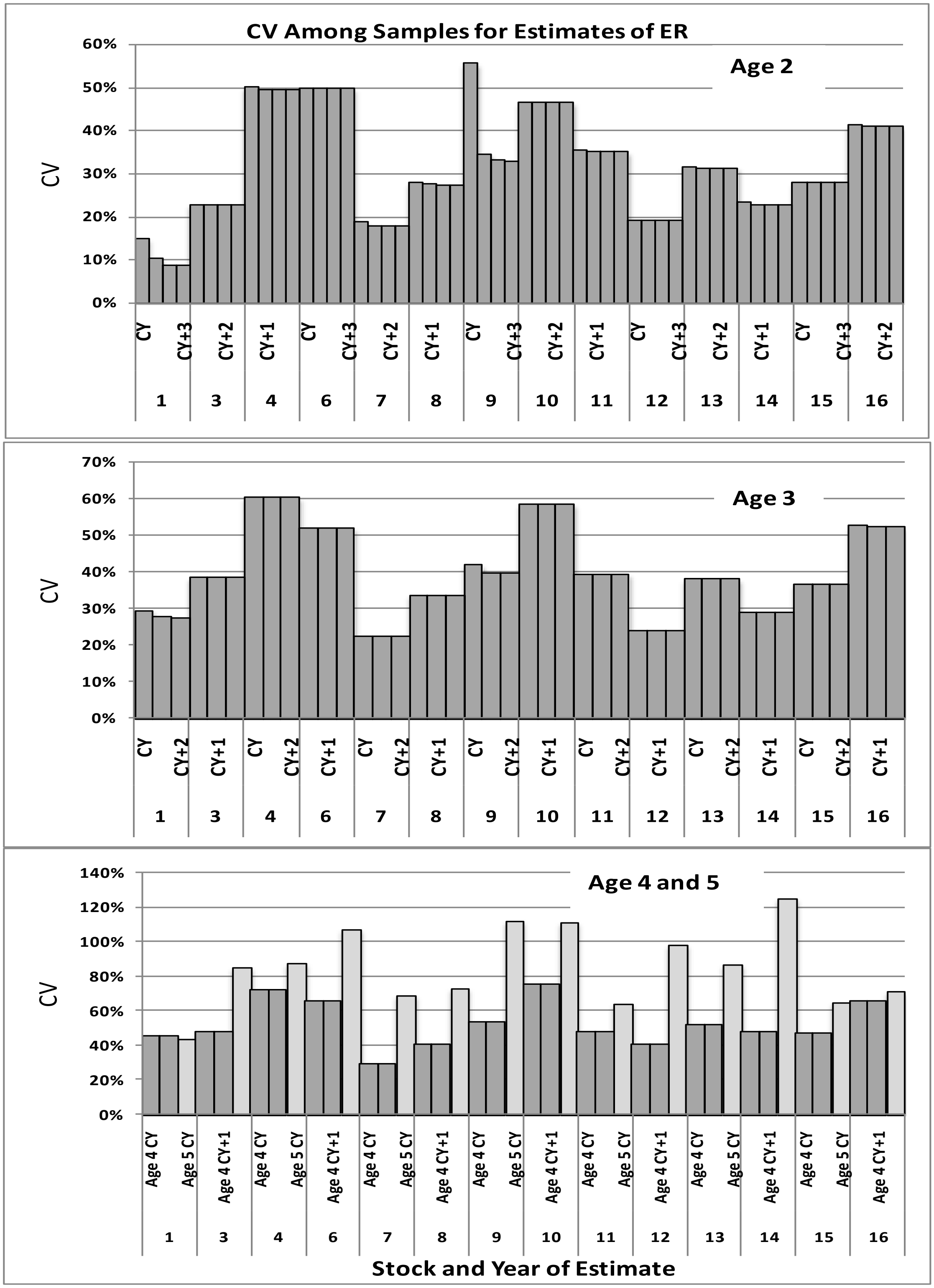


Figure 3-5. Variability among samples for estimated ERs by age. The CV for the estimated ER is averaged over iteration, catch year, fishery and period by stock and year of estimate. For age 2 the estimates are incomplete until catch year+3 (CY+3) when all recoveries from all ages in the brood are available, for age 5 there is a single complete estimate in the catch year.

Ages 4 and particularly 5 provide the least precise estimates, i.e., the largest CV among iterations and among samples as the cohort sizes available for these ages are smallest resulting in larger process error and a smaller number caught, a lower number of tagged fish in samples and higher sampling error (Figure 3-4 and Figure 3-5).

3.5.2 Relative Error

Relative error (RE) is the comparison of the estimated ER to the true value of the ER for each iteration and is measured for the estimate of ER from the *jth* sample in the *ith* iteration by,

$$RE_{ij} = \frac{\hat{E}R_{ij} - ER_i}{ER_i} * 100 \qquad (3\text{-}16)$$

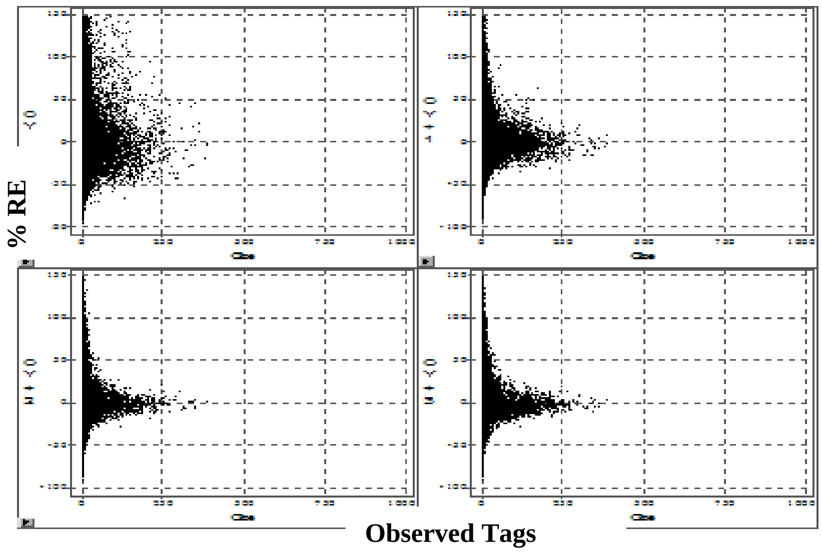
where ER_i is the true value of the ER for iteration *i* and $\hat{E}R_{ij}$ is the estimated ER for sample *j* in iteration *i*.

Figure 3-6 shows the distribution of the relative errors in the estimates of ER versus the observed tags in the sample of the fishery for which the ER is estimated (i.e., the numerator of the ER equation) for stocks 9 and 12, the smallest and largest stocks (Figure 3-1). This exhibits the expected pattern with the relative error decreasing as the observed tags increases (PSC 2008). For each stock there are four plots, showing the relative error for the estimates of ER for a catch year over the four years it takes to acquire tag recoveries for complete estimates on all ages, i.e., the estimate of cohort size is based on tag recoveries of all ages in the brood. In general, the scatter is widest in the first year and smallest in the fourth year when all estimates are complete estimates (Figure 3-6).

If, on average, the RE is equal to zero, then the estimate of ER is unbiased, but if the average is different from zero then this indicates a bias (Table 3-4). All fishery/periods with zero ER were excluded from these averages. For age 2 estimates of ER are incomplete until the fourth year after the catch year, when tag recoveries are available for all ages in the brood, whereas for age 5 a complete estimate is available in the catch year as it is only based on age 5 recoveries in the catch year. The first estimate for age 2 ERs are only based on recoveries of age 2 fish, so the estimate of cohort size (in the denominator of the ER) is derived using average maturation rate for age 2 and for age 5 the estimates are based only on age 5 tagged recoveries.

Table 3-4 shows the mean and median for all stocks in all cases the RE is highest for the first estimate in the catch year (CY and YR1) and decreases in subsequent estimate years (Table 3-4) as the estimates are based on more information, i.e., larger number of tags recovered for the brood. The RE for the estimate of ER is increases as the number of recovered tags used in the estimate, e.g., for age 5 and for stocks with smaller cohort sizes. Stocks 4 and 9 have small cohort sizes (Figure 3-1) and a larger RE compared to stock 12 which has the largest cohort size in the simulation (Table 3-4). For all stocks the median is closer to zero than the mean (Figure 3-6).

Stock 9



Stock 12

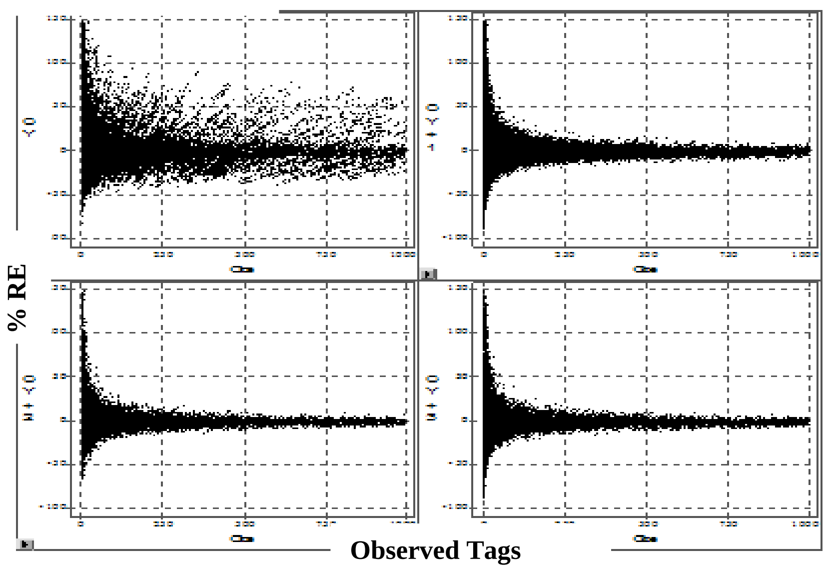


Figure 3-6. Percent relative error plotted against observed tags for the estimates of ER for stocks 9 (upper) and 12 (lower), which have the smallest and largest number of observed tags in fisheries. Each point represents an estimate of ER for a time period, fishery, catch year, sample and iteration. For each stock the relative error of the ER estimates are shown for the catch year (CY in the upper left panel) and the following three years(CY+1 in the upper right panel, CY+2 in the lower left panel and CY+3 in the lower right panel). The number of observed tags ranges from 0 to 1,000 In the catch year only age 5 has complete data, while the age 2 estimate of ER is not based on complete data until year CY+3.

Table 3-4. Mean and median percent relative error by stock and for four estimates of ER made from data available in the catch year (CY) and subsequent three years (CY+yr). The relative error is averaged over the samples within iteration, fishery and period and the mean and median derived for these means.

Stock	Age	Mean				Median			
		CY	CY+1	CY+2	CY+3	CY	CY+1	CY+2	CY+3
1	2	7.2	-0.5	-1.5	-1.5	5.6	-0.7	-1.2	-1.2
	3	31.4	28.1	27.9	.	6.4	2.6	2.2	.
	4	33.9	33.6	.	.	3.5	3.3	.	.
	5	30.5	.	.	.	5.2	.	.	.
3	2	12.1	10.4	9.1	9.1	4.0	2.0	0.2	0.1
	3	24.5	21.9	21.9	.	8.8	5.4	5.4	.
	4	29.1	29.1	.	.	9.2	9.2	.	.
	5	46.3	.	.	.	31.0	.	.	.
4	2	21.8	16.9	15.6	15.6	20.1	15.3	14.0	14.0
	3	22.3	20.4	20.4	.	21.1	19.3	19.5	.
	4	24.0	23.8	.	.	23.4	22.7	.	.
	5	29.1	.	.	.	27.2	.	.	.
6	2	18.2	14.0	13.2	13.2	16.6	13.1	12.7	12.7
	3	14.8	13.5	13.5	.	14.1	12.9	12.7	.
	4	20.4	20.4	.	.	21.0	21.2	.	.
	5	42.3	.	.	.	40.0	.	.	.
7	2	14.3	3.3	1.2	1.2	13.3	2.2	0.0	-0.1
	3	4.6	2.3	2.4	.	3.2	0.4	0.5	.
	4	3.9	4.0	.	.	1.4	1.5	.	.
	5	20.4	.	.	.	14.3	.	.	.
8	2	11.8	5.1	3.2	3.3	10.7	3.5	1.1	1.1
	3	8.7	6.1	6.1	.	6.7	3.9	3.7	.
	4	8.6	8.6	.	.	6.9	6.8	.	.
	5	22.2	.	.	.	20.1	.	.	.
9	2	65.7	14.4	12.0	12.1	51.6	5.5	3.4	3.5
	3	19.8	15.6	15.7	.	10.8	5.6	5.7	.
	4	18.1	18.2	.	.	10.0	10.2	.	.
	5	44.7	.	.	.	42.0	.	.	.
10	2	21.1	19.4	18.1	18.2	11.2	9.4	8.4	8.3
	3	25.0	23.3	23.3	.	17.9	15.9	15.8	.
	4	32.8	32.9	.	.	26.0	25.7	.	.
	5	39.0	.	.	.	35.8	.	.	.
11	2	10.7	8.4	6.5	6.6	9.7	7.0	4.7	4.6
	3	10.8	8.7	8.8	.	9.8	6.7	6.8	.
	4	11.9	11.9	.	.	10.5	10.5	.	.
	5	19.2	.	.	.	18.0	.	.	.

Stock	Age	Mean				Median			
		CY	CY+1	CY+2	CY+3	CY	CY+1	CY+2	CY+3
12	2	6.0	2.0	2.0	2.0	5.2	0.2	0.2	0.1
	3	3.5	3.7	3.7	.	0.6	0.5	0.5	.
	4	11.1	11.1	.	.	1.6	1.6	.	.
	5	39.8	.	.	.	31.8	.	.	.
13	2	10.7	6.2	6.0	5.9	7.7	2.7	2.0	1.9
	3	8.9	8.8	8.8	.	4.6	4.7	4.7	.
	4	12.7	12.6	.	.	8.3	8.4	.	.
	5	29.9	.	.	.	27.2	.	.	.
14	2	10.5	0.9	1.0	1.1	10.4	-0.1	-0.1	-0.1
	3	3.5	3.2	3.2	.	1.4	1.1	1.1	.
	4	10.0	10.1	.	.	6.6	6.7	.	.
	5	70.6	.	.	.	55.8	.	.	.
15	2	8.2	6.2	5.6	5.6	4.1	1.9	1.2	1.0
	3	10.0	9.4	9.2	.	5.1	3.8	3.7	.
	4	14.0	13.5	.	.	8.1	7.4	.	.
	5	23.0	.	.	.	17.3	.	.	.
16	2	13.2	10.7	10.0	11.0	10.7	8.7	7.8	9.0
	3	16.4	15.1	16.6	.	15.5	13.9	14.9	.
	4	19.6	21.7	.	.	18.7	20.6	.	.
	5	3.1	.	.	.	2.2	.	.	.

3.5.3 Complete vs. Incomplete estimates of ER

Estimates of ER are made for all ages caught in a catch year. However, except for the age 5 estimates, the tag data are not available for all ages for the broods present in a catch year. Incomplete estimates of ER are made for ages 2-4 using maturation rates to estimate the number of fish remaining after preterminal fisheries reduced by the mature run (see equations 3-2 to 3-5 in section 3.2). This allows estimation of the cohort size without tag recoveries of older ages which will be available over the following three years. Thus for instance in the catch year the estimate of age 2 ER is made using an average maturation rate for age 2 for a stock and the age 2 tags caught. The question then is of what quality are these early, incomplete, estimates. The previous section provides some information as the relative error generally decreases from the first estimate in the catch year to the complete estimates 1-3 years later (depending on the age). Another measure is to evaluate the incomplete estimates relative to the complete as,

$$Diff_{ijk} = \frac{\hat{E}R_{ijk} - \hat{E}R_{ijc}}{\hat{E}R_{ijc}} * 100 \qquad (3\text{-}17)$$

where $\hat{E}R_{ijk}$ is the kth incomplete estimate of ER and $\hat{E}R_{ijc}$ is the complete estimate. For age 2, k=1 to 3, for age 3, k is 1 to 2 and for age 4 k=1. This provides a measure of stability of the estimate of ER as the wider the distribution of the estimates over the iterations and samples the bigger the difference is between initial incomplete estimates and the final estimate based on all tag data for a brood.

Figure 3-7 shows the percent difference between incomplete and complete estimates by age and stock. Catch years, fisheries and periods are combined as the patterns are similar with the age and stock. The distribution varies among the ages, with age 2 having the widest distribution for the initial estimate in the catch year ranging about ±25% and the average difference is consistently larger than zero (Figure 3-8) for this age. For age 3 the difference in the initial estimate ranges about ±10%, while for age 4 the % difference is very small. The variability decreases as additional ages are added for the estimate, Basically for each age the difference is very small (<±5%) in the year prior to the year when complete data are available which is in the catch year for age 4, catch year+1 for age 3 and catch year+2 for age 2.

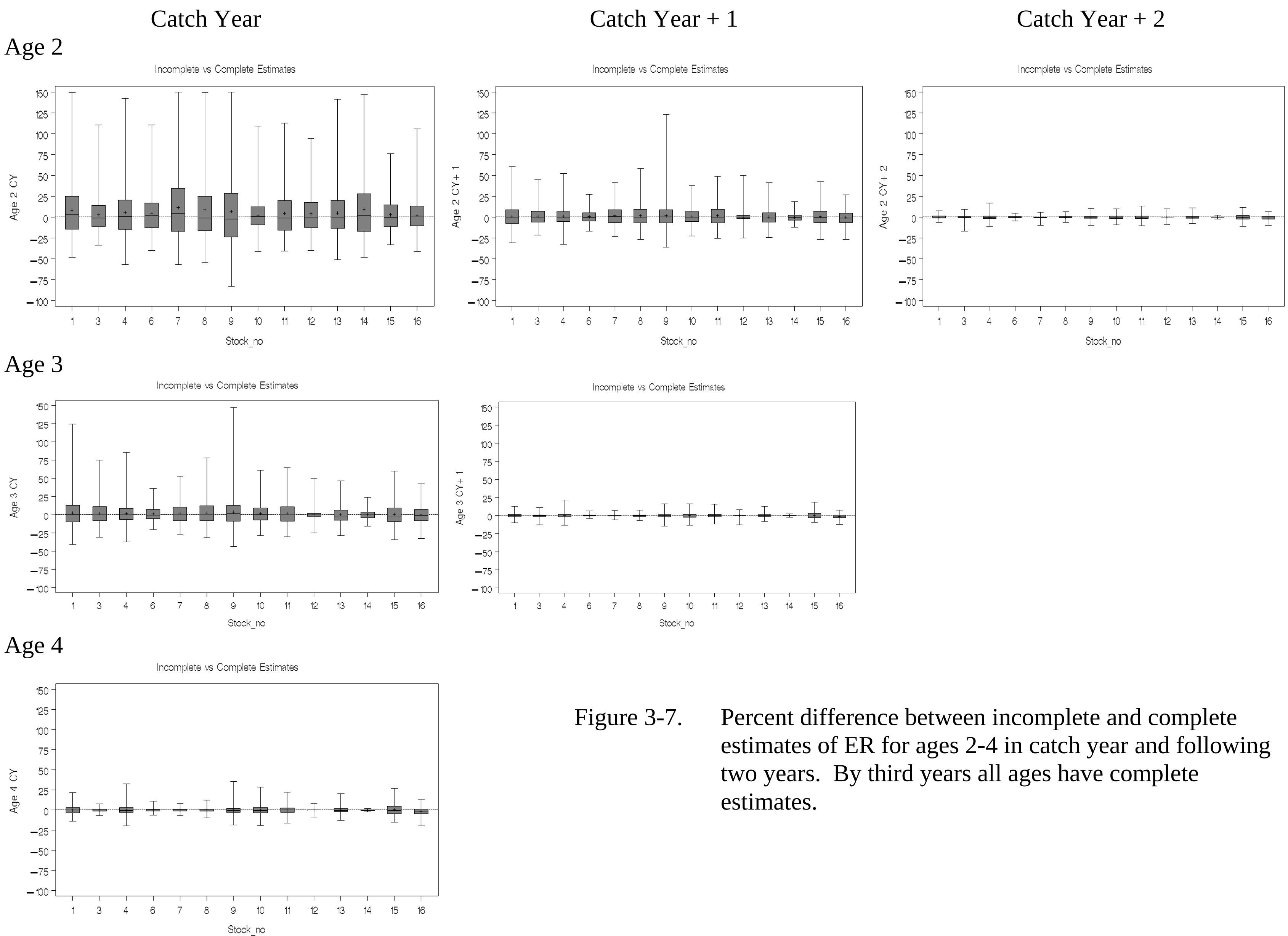


Figure 3-7. Percent difference between incomplete and complete estimates of ER for ages 2-4 in catch year and following two years. By third years all ages have complete estimates.

Chapter 4. Harvest Rate Metrics

4.1 Alternative Fishery HRIs estimated

Since the mid 1980s, the CTC has employed HRIs to report relative changes in fishery harvest rates under PSC regimes (TCCHINOOK 1988, Appendix II). Indices were used because methods to estimate fishery harvest rates were unavailable. The CTC's HRI metrics are typically computed as ratios of ERs derived from CWT-based cohort analysis (see Chapter 3) for a catch year of interest divided by the average observed during a selected base period. Consequently, an HRI >1 indicates a higher harvest rate while an HRI <1 indicates a lower harvest rate relative to the base period harvest rate.

The Support Group evaluated three HRI metrics that have been previously investigated or reported by the CTC when presenting the results of its annual CWT-based ER analysis: the Simple Average (SA), the Ratio of Means (ROM), and the Stratified Proportional Fishery Index (SPFI).

The SA and ROM are technically ERIs since they are computed as ratios of ERs. The ER for a fishery, year, stock and age is the proportion of the total vulnerable cohort that is taken in a fishery and is a function of the catch, the cohort size and the proportion vulnerable for the stock and age in the fishery and year of interest, $ER = \frac{C}{PV * COH}$, and is typically estimated as $ER = \frac{CWT}{PV * cwtCOH}$. In contrast, the HR accounts for the portion of the vulnerable cohort actually present in the fishery and is therefore available to be harvested. Thus, the calculation of an HR requires all the same information as an ER plus information on the distribution of the stock and age in the fishery, $HR = \frac{C}{D * PV * COH}$. In the case of the SA and ROM, the distribution of stocks and ages in a fishery is assumed to be static from year to year and therefore the distribution parameter (*D*) in the denominator of the HR for any year of interest is cancelled by the distribution parameter in the denominator of the base period HR when calculating the HRI. This results in the formulations for the ERI and HRI being equivalent. Therefore, the SA and ROM can be considered HRI metrics.

4.1.1 Base Period and Catch Year Data

Two years, 1982 and 1983, were used as the base period for computing HRI metrics. In order to minimize potential instability in the metrics resulting from small numbers of CWT recoveries in a simulated fishery, the Support Group selected only those stocks and ages that had an average of 35 or more estimated CWT recoveries during the base period years (all CWT recoveries during a catch year, Oct-Sep, are pooled). This criterion is consistent with that employed by the CTC in computing HRIs to eliminate stock-age combinations with recovery rates that may not reflect typical fishery impacts. The criteria were derived from research completed by Frank deLibero (deLibero 1986), based on an assumed 20% minimum sampling rate and a maximum acceptable CV of 35% for an estimate of total ER.

The average base period ER is calculated for each stock-age combination as:

$$bpER_{f,s,a} = \frac{\sum_{y=1982}^{1983} ER_{f,y,s,,a}}{m} \tag{4-1}$$

where m represents the number of base period years that are included (usually = 2 in the simulation, but in some cases, the average criterion could be satisfied when one year may have no data while the second year has over 70 CWTs).

4.1.2 Simple Average (SA)

The CTC employed the SA to report relative changes in fishery harvest rates in 1985 through 1987. Individual catch year stock and age-specific indices (*cyERIs*) are calculated by dividing an annual ER by its corresponding base period average:

$$cyERI_{f,y,s,a} = \frac{ER_{f,y,s,a}}{bpER_{f,s,a}} \tag{4-2}$$

The SA HRI metric ($saERI_{f,y}$) for the fishery and year is the average over all selected stock and age combinations:

$$saERI_{f,y} = \frac{1}{n} \sum_{s,a \in n} cyER_{f,y,s,a} \tag{4-3}$$

where n is the number of the catch year indices that meet the minimum criteria for CWT recoveries (the notation beneath the summation symbol, $s,a \in n$, indicates the stock-age combinations meeting the criterion).

4.1.3 Ratio of Means (ROM)

Beginning in 1987, the CTC relied upon the *ROM* metric to report relative changes in fishery harvest rates. It is computed as the ratio of the sum of the stock age ERs in the current year over the sum of the ERs in the base years:

$$romERI_{f,y} = \frac{\sum_{s,a \in n} ER_{f,y,s,a}}{\sum_{s,a \in n} bpER_{f,s,a}} \tag{4-4}$$

using the stock and age combinations ($s,a \in n$) that meet the minimum CWT recovery criteria.

4.1.4 Stratified Proportional Fishery Index (SPFI)

In the mid-1990s, the CTC became concerned that the ROM may not be suitable for reporting relative fishery harvest rates for the SEAK troll fishery due to changes in fishing patterns. The CTC developed a Stratified Proportional Fishery Index (SPFI) to account for differences in stock compositions due to the timing and location of fishing. Recoveries for the SEAK troll fishery were accounted for in six time and area strata: Winter/Spring, June Inside, June Outside, July Inside, July Outside, and Fall. The SPFI method re-integrates the recoveries in each of these strata so as to produce a standardized index for reporting annual changes in fishery harvest rates. The CTC has used the SPFI to report changes in the fishery harvest rate for the SEAK troll fishery since 1996. Although the SPFI has only been used in the SEAK troll fishery to date it could easily be adapted for use in the other AABM fisheries.

Fishery ERs vary by stock and age. In contrast, the harvest rate (HR) for a fishery is presumed to be the same for all vulnerable fish. For a given year, stock, age, and stratum, the harvest rate is:

$$HR_{f,y,x} = \frac{ER_{f,s,y,a,x}}{PV_{f,s,a} * D_{f,s,a,x}} = \frac{C_{f,y,s,a,x}}{COH_{y,s,a} * PV_{f,s,a} * D_{f,s,a,x}} \tag{4-5}$$

Because the HR is assumed to be identical for all stocks and ages in a given strata, the SPFI method estimates a relative harvest rate using the distribution parameter D. Rearranging the above equation, D is:

$$D_{f,s,a,x} = \frac{C_{f,y,s,a,x}}{COH_{y,s,a} * PV_{f,s,a} * HR_{f,y,x}} \tag{4-6}$$

The CTC’s current ER analysis procedures assume that the proportion vulnerable (PV) is identical for all stocks of a given age encountered in a fishery. In contrast, the simulation model uses stock-specific estimates of means and standard deviations of length at age. The distribution and proportion vulnerable parameters are confounded. In the SPFI method, these two parameters are combined into a new distribution parameter D’:

$$D'_{f,s,a,x} = D_{f,s,a,x} * PV_{f,s,a} \tag{4-7}$$

Equation 4-7 can be written as:

$$D'_{f,s,a,x} = \frac{C_{f,y,s,a,x}}{COH_{y,s,a} * HR_{f,y,x}} \tag{4-8}$$

If the strata specific harvest rates on the tagged fish are representative of all fish in the strata then the strata specific abundances can be estimated as:

$$\tilde{N}_{f,y,x} = \frac{C_{f,y,x}}{HR_{f,y,x}} \qquad (4\text{-}9)$$

The SPFI method assumes that the D' for the stock-age group with the largest estimated distribution in a particular stratum is equal to 1.0, and computes a relative D' for other stock-age groups impacted by the fishery. Since HR and D' are each functions of the other, the calculation of the SPFI involves an iterative process that continues until the change in each stock-age distribution parameter is less than some specified tolerance level. Setting the largest stock-age D' in a stratum equal to 1.0 is equivalent to assuming that this stock-age combination is fully available to that fishery stratum. This assumption is necessary in order to achieve a unique solution during the iterative process.

Because the SPFI estimates a relative fishery harvest rate, this metric does not require CWT data to be available for stock-age combinations in both the base period and the year of interest. The formulation of the SPFI allows for the use of any or all CWT recoveries in the fishery regardless of the availability of CWT recoveries in the base period. This is a departure from the ROM and SA HRIs that require stock-age CWT recoveries used in any year have corresponding stock-age recoveries during the base period. However, historically, the Alaska troll SPFI has been applied using only those stocks and ages that have a long-term average of at least 35 estimated CWT recoveries per year.

Data required for the CTC to compute the SPFI consist of output files produced by the cohort analysis and reported treaty catches. In its annual CWT ER analysis, nominal values are converted into adult equivalents for the SPFI estimation procedure. An adult equivalent is the probability that a fish alive at the start of a given time period would survive to return to its river of origin in the absence of fishing in the current and future years. The conversion to adult equivalences is done to standardize the exploitation rates in ocean and terminal fisheries.

When data are available for several years, using an analog to equation 4-8, the distribution parameter is estimated by,

$$D'_{f,s,a,x} = \frac{\sum_{y} CWT_{f,y,s,a,x}}{\sum_{y} \left(cwtHR_{f,y,x} * cwtCOH_{y,s,a} \right)} \qquad (4\text{-}10)$$

The largest stock-age distribution parameter in a stratum is set to 1.

The CWT HR is estimated using,

$$cwtHR_{f,y,x} = \frac{\sum_{s}\sum_{a} CWT_{f,y,s,a,x}}{\sum_{s}\sum_{a} \left(D'_{f,s,a,x} * cwtCOH_{y,s,a} \right)} \qquad (4\text{-}11)$$

The AEQ Stratum Harvest Rate is estimated by,

$$HR_{f,y,x} = \frac{\left[\left(\frac{\sum_s\sum_a aeqCWT_{f,y,s,a,x}}{\sum_s\sum_a CWT_{f,y,s,a,x}}\right)*C_{f,y,x}\right]}{\left(C_{f,y,x}/cwtHR_{f,y,x}\right)} = \left(\frac{\sum_s\sum_a aeqCWT_{f,y,s,a,x}}{\sum_s\sum_a CWT_{f,y,s,a,x}}\right)*cwtHR_{f,y,x} \tag{4-12}$$

The AEQ Fishery Harvest Rate is,

$$HR_{f,y} = \frac{\sum_x\left[\left(\frac{\sum_s\sum_a aeqCWT_{f,y,s,a,x}}{\sum_s\sum_a CWT_{f,y,s,a,x}}\right)*C_{f,y,x}\right]}{\sum_x \left(C_{f,y,x}/cwtHR_{f,y,x}\right)} \tag{4-13}$$

The strata specific HRIs are calculated as,

$$HRI_{f,y,x} = \frac{HR_{f,y,x}}{\left(\sum_{b=1979}^{1982} HR_{f,b,x} \Big/ 4\right)} \tag{4-14}$$

And the Stratified Proportional Fishery Index is,

$$SPFI_{f,y} = \frac{HR_{f,y}}{\left(\sum_{b=1979}^{1982} HR_{f,b} \Big/ 4\right)} \tag{4-15}$$

In the simulations used to evaluate alternative HRIs, two different SPFI estimators were produced. The first estimator used stocks and ages that averaged 35 CWT recoveries during the 1982 to 1983 base period and the second estimator used stocks and ages that averaged at least 35 CWT recoveries across all years.

4.2 Model Performance and Evaluation

4.2.1 Stability and Variation

We investigated the performance of the simulation model due to its' complex and stochastic structure, the diversity of data inputs and the large volume of results generated from each simulated scenario. There were many aspects of the results that were examined but we focused on those relevant to real world management: magnitude and variability in the annual total fishery catches, the fishery harvest rates and the HR metrics computed from the stock- and age-specific estimated CWT catches. In particular, we investigated changes in magnitude and variability in relation to the two major management actions introduced after the base period years: 1) the shifting of seasonal impacts away from the summer period to a split between the spring and fall periods in fishery 4 in both simulation scenarios, and 2) the overall reduction in the fishery harvest rates (and catches) in all four fisheries under scenario 2.

4.2.1.1 Catches and Harvest Rates Resulting from the Simulations

The annual catches averaged the highest in fishery 1 and lowest in fishery 2 with similar CVs for each under scenario 1 (Table 4-1). The catches in fisheries 3 and 4 were intermediate on average between the other two fisheries as well as being identical as intended. The annual variability in catches of fisheries 3 and 4 was much greater (Figure 4-1), however, with both the minimum and maximum catches exceeding the ranges of fisheries 1 and 2. The averages and ranges for all four fisheries were similar for the two base period years (1982 and 1983) under scenario 2 compared to all years under scenario 1. Possibly in relation to the greater annual variability observed for fisheries 3 and 4, the annual catch distributions showed notable skew, though not consistent in magnitude or direction (Figure 4-1). The variability in the distributions of annual fishery catches under both scenarios reveals the effect of the stochasticity associated with many of the input data to the simulations.

Catch averages for all four fisheries decreased under scenario 2 following the harvest rate reductions imposed after the base period years (Figure 4-1). The catches in fisheries 3 and 4 then averaged the lowest, consistent with the greater harvest rate (HR) reductions in those two fisheries, but variability as expressed by the CV, remained the highest. The CVs and ranges for fisheries 1 and 2 remained about the same before and after the HR reductions. Following the HR reductions, the smallest catches were observed in fisheries 3 and 4. The maximum catches in those fisheries only exceeded those in fishery 2 by a modest margin (<35,000). The true annual harvest rates followed similar patterns as the catches between scenarios and among fisheries and years and (Table 4-2).

The HR reductions under scenario 2 were implemented in the simulations through HR scalars (Table 2-2) which were decreased by 30% for fisheries 1 and 2 and 70% for fisheries 3 and 4. The reductions in the HR scalars translated into similar but not identical reductions in the true annual HRs and fishery catches generated by the simulation program (Table 4-3). The reductions in the HRs averaged approximately 25% and 27% for fisheries 1 and 2, respectively, and 60% for both fisheries 3 and 4. The corresponding decreases in catch were not quite so great, averaging about 20% for fisheries 1 and 2 and 57% for fisheries 3 and 4. Thus, responses to manipulations of the HR scalars were not quite the same in the realized HRs and catches. For reasons not yet

Table 4-1. Mean annual true fishery catch and coefficient of variation by fishery, year and scenario. N = 25.

		Fishery 1		Fishery 2		Fishery 3		Fishery 4	
Scenario	**Year**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1	1982	417,769	8.67%	176,830	10.30%	286,651	68.06%	286,651	68.06%
	1983	410,211	13.76%	170,539	11.70%	213,189	69.61%	213,189	69.61%
	1985	418,767	10.64%	171,050	11.43%	357,203	46.39%	357,203	46.39%
	1986	407,215	9.90%	165,630	10.62%	224,649	48.23%	224,649	48.23%
	1991	439,053	9.70%	181,032	10.50%	240,582	71.63%	240,582	71.63%
	1992	429,401	7.89%	177,914	10.64%	241,519	61.68%	241,519	61.68%
2	1982	409,199	10.55%	169,731	13.41%	232,623	63.18%	232,623	63.18%
	1983	426,804	8.79%	174,293	9.21%	342,258	50.92%	342,258	50.92%
	1985	318,216	8.95%	131,497	8.10%	99,666	55.19%	99,666	55.19%
	1986	344,424	8.77%	137,311	9.70%	109,525	41.90%	109,525	41.90%
	1991	331,110	10.41%	135,015	10.40%	115,170	40.65%	115,170	40.65%
	1992	334,767	10.66%	133,914	10.31%	114,249	46.53%	114,249	46.53%

Table 4-2. Mean annual true fishery harvest rate and coefficient of variation by fishery, year and scenario. N = 25.

		Fishery 1		Fishery 2		Fishery 3		Fishery 4	
Scenario	**Year**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1	1982	0.3955	7.72%	0.1598	7.53%	0.1989	64.87%	0.1989	64.87%
	1983	0.3891	9.61%	0.1563	9.55%	0.1534	64.20%	0.1534	64.20%
	1985	0.3913	7.50%	0.1526	7.40%	0.2443	43.44%	0.2443	43.44%
	1986	0.3834	6.53%	0.1495	6.85%	0.1613	47.31%	0.1613	47.31%
	1991	0.3990	7.93%	0.1568	7.86%	0.1672	65.70%	0.1672	65.70%
	1992	0.4009	6.26%	0.1577	8.67%	0.1687	56.45%	0.1687	56.45%
2	1982	0.3799	7.35%	0.1504	7.84%	0.1583	59.82%	0.1583	59.82%
	1983	0.4037	6.41%	0.1593	7.66%	0.2339	45.72%	0.2339	45.72%
	1985	0.2815	8.10%	0.1119	8.65%	0.0670	51.85%	0.0670	51.85%
	1986	0.2924	7.51%	0.1122	7.68%	0.0719	38.88%	0.0719	38.88%
	1991	0.2937	8.78%	0.1141	7.77%	0.0772	39.33%	0.0772	39.33%
	1992	0.2960	7.69%	0.1129	7.31%	0.0749	43.34%	0.0749	43.34%

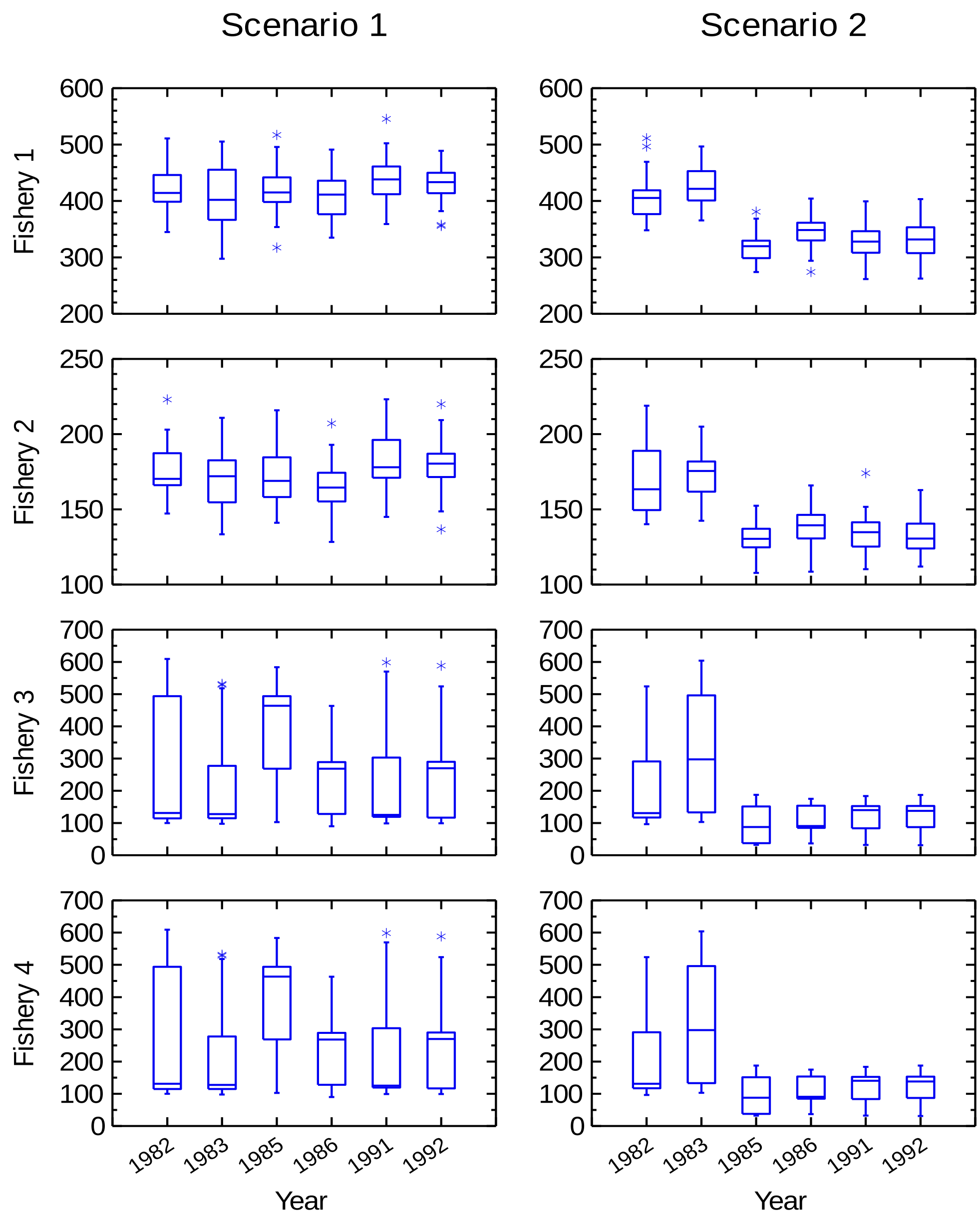


Figure 4-1 Box plot distributions of true annual fishery catch under the two scenarios. Catch distributions for each fishery for the six selected years are displayed in a row of two panels, one for each scenario. The horizontal line within boxes is the median; the lower and upper margins of boxes mark the range of the central 50% of values (i.e., they bound the 2nd and 3rd quartiles of the distribution). The lower and upper vertical extensions (i.e., 'whiskers') on boxes mark the range of values within 1.5 times the width of the lower and upper sections of boxes. Outliers beyond whiskers are within 3 times these widths. N = 25 for each box plot. The y-axis represents numbers of fish in thousands.

understood, the reductions in HRs and catches deviated further from the reduction in the HR scalar for fisheries 3 and 4 compared to fisheries 1 and 2 but, the correspondence between HR and catch changes was closer (Figure 4-2, see the Scenario 2 panel). There were no specific manipulations of the HR scalars implemented in any year under scenario 1. Nevertheless, both average HRs and catches varied from year to year. These variations were quite large relative to the base period average for fisheries 3 and 4 (max 68%; Table 4-3). Presumably, they reflect the stochastic potential associated with the data inputs.

4.2.1.2 HR Metrics Calculated from the Simulation Data

In this section, we summarize some basic statistical features of the three HR metrics, the SPFI, SA and ROM, calculated from the estimated CWT data generated by the simulations. In addition, we investigate correspondence of the metrics to major differences among the fisheries and to the previously mentioned management actions introduced in each scenario. We also compare select characteristics underlying all three metrics with the ROM metric as calculated for the actual WCVI AABM fishery. A statistical comparison of the relative performance of the three metrics is left to the next section.

All three metrics show relatively similar distributions (i.e., almost completely overlapping) when compared to each other by fishery, year and scenario (Figure 4-3). Regardless of the metric, the distributions for the two base period years, 1985 and 1986, are similar to each other but differ from the later years. This is because data from each base period year contributes to the denominator for all years, but to the numerator only for base period years in the calculation of each metric (see equations 4-2, 4-4 and 4-15). Under scenario 1, the distributions and mean values (Table 4-4) of the metrics are relatively stable across years for fisheries 1 and 2 despite differences in fishery characteristics such as average size of the catch. This observation is also true under scenario 2 after the base period years. The same observations apply in comparing fishery 3 with fishery 4. Bear in mind that unlike the harvest rates and catches for these two fisheries, the HR metrics were not constrained to be identical. The effect of the differences in seasonal pattern of catches could have resulted in quite dissimilar values for fishery 3 compared to fishery 4 but only minor differences are detectable, primarily in the outliers (see Figure 4-3).

Despite relative stability across years, the distributions of all three metrics are much broader for fisheries 3 and 4 and the averages more variable between years compared to the other two under both scenarios (Figure 4-3, Table 4-4). This is associated with the greater variability in catch observed in these two fisheries and the correlation between each metric and catch is stronger for fisheries 3 and 4 compared to fisheries 1 and 2 (Figure 4-4). The correlation between catch and each metric is stronger under scenario 2 for all of the fisheries but even more so for fisheries 3 and 4. This is likely due to the decrease in frequency of outliers with the reductions in harvest rates and catches after the base period. The SA metric only is shown in Figure 4-4 but graphs of the SPFI and ROM are highly similar and lead to the same observations.

Table 4-3 Mean percentage change in the true annual catches and fishery harvest rates relative to the average of the two base period years for each fishery, year and scenario. Mean values for the two transition (TR) years, 1985 and 1986, and the two post-transition (PT) years, 1991 and 1992, are also given. Positive values represent an increase compared to the base period average, negative values a decrease.

		Fishery 1		Fishery 2		Fishery 3		Fishery 4	
Scenario	**Year**	**HR**	**Catch**	**HR**	**Catch**	**HR**	**Catch**	**HR**	**Catch**
1	1985	0.1	2.0	-3.3	-1.1	60.2	68.3	60.2	68.3
	1986	-2.0	-0.9	-5.3	-4.0	6.7	7.4	6.7	7.4
	1991	2.1	7.4	-0.5	5.1	10.9	11.5	10.9	11.5
	1992	2.6	5.1	0.0	3.4	20.8	23.2	20.8	23.2
	TR mean	-0.9	0.5	-4.3	-2.6	33.4	37.8	33.4	37.8
	PT mean	2.3	6.2	-0.3	4.2	15.8	17.3	15.8	17.3
2	1985	-27.9	-23.4	-27.5	-22.7	-63.4	-61.4	-63.4	-61.4
	1986	-25.0	-16.9	-27.2	-19.1	-58.8	-54.9	-58.8	-54.9
	1991	-24.8	-20.1	-26.1	-20.9	-58.0	-55.4	-58.0	-55.4
	1992	-24.2	-19.3	-26.8	-21.4	-59.6	-55.9	-59.6	-55.9
	TR mean	-26.5	-20.1	-27.3	-20.9	-61.1	-58.1	-61.1	-58.1
	PT mean	-24.5	-19.7	-26.4	-21.1	-58.8	-55.7	-58.8	-55.7

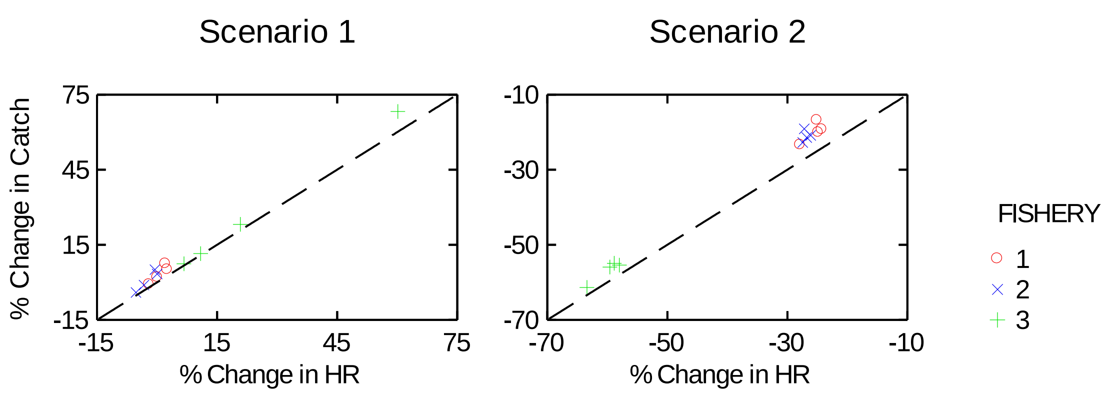


Figure 4-2. Correspondence between the average change in the fishery harvest rates and the average change in true fishery catches relative to the base period average under both scenarios. The diagonal dashed lines indicate perfect correspondence. Both the x- and y-axis scales differ between panels. Fisheries are indicated by different symbols. Values for fisheries 3 and 4 are identical, therefore, only those for fishery 3 are displayed.

Table 4-4 Mean values of the SPFI, SA and ROM by fishery, year and scenario. N = 250.

		Fishery 1			Fishery 2			Fishery 3			Fishery 4		
Scenario	Year	SPFI	SA	ROM	SPFI	SA	ROM	SPFI	SA	ROM	SPFI	SA	ROM
1	1982	1.002	0.997	0.975	1.008	1.008	0.997	1.087	1.083	1.081	1.087	1.080	1.076
	1983	0.998	1.003	1.025	0.992	0.992	1.003	0.913	0.917	0.919	0.913	0.920	0.924
	1985	1.005	1.119	1.031	0.973	1.046	0.947	1.557	1.738	1.557	1.516	1.820	1.597
	1986	0.991	1.091	1.003	0.954	1.007	0.914	1.048	1.147	1.021	1.016	1.161	1.035
	1991	1.025	1.121	1.009	1.000	1.080	0.971	1.078	1.166	1.048	1.045	1.216	1.069
	1992	1.032	1.149	1.043	1.012	1.066	0.957	1.198	1.301	1.140	1.160	1.327	1.167
2	1982	0.970	0.966	0.925	0.983	0.976	0.969	0.817	0.821	0.825	0.818	0.813	0.817
	1983	1.030	1.034	1.075	1.017	1.024	1.031	1.183	1.179	1.175	1.182	1.187	1.183
	1985	0.708	0.794	0.700	0.720	0.761	0.681	0.365	0.417	0.365	0.349	0.399	0.356
	1986	0.740	0.819	0.727	0.724	0.767	0.703	0.410	0.453	0.407	0.394	0.462	0.405
	1991	0.743	0.801	0.706	0.743	0.774	0.692	0.418	0.456	0.411	0.407	0.457	0.406
	1992	0.750	0.801	0.693	0.726	0.751	0.663	0.405	0.442	0.396	0.391	0.459	0.402

Table 4-5 Mean percent change in the HR metrics following the base period years under both scenarios. Mean values for the two transition (TR) years (1985 and 1986) and the two post-transition (PT) years (1991 and 1992) are given.

		Fishery 1			Fishery 2			Fishery 3			Fishery 4		
Scenario	Year	SPFI	SA	ROM	SPFI	SA	ROM	SPFI	SA	ROM	SPFI	SA	ROM
1	1985	0.5	11.9	3.1	-2.7	4.6	-5.3	55.7	73.8	55.7	51.6	82.0	59.7
	1986	-0.9	9.1	0.3	-4.6	0.7	-8.6	4.8	14.7	2.1	1.6	16.1	3.5
	1991	2.5	12.1	0.9	0.0	8.0	-2.9	7.8	16.6	4.8	4.5	21.6	6.9
	1992	3.2	14.9	4.3	1.2	6.6	-4.3	19.8	30.1	14.0	16.0	32.7	16.7
	TR mean	-0.2	10.5	1.7	-3.7	2.7	-7.0	30.3	44.3	28.9	26.6	49.1	31.6
	PT mean	2.8	13.5	2.6	0.6	7.3	-3.6	13.8	23.4	9.4	10.3	27.2	11.8
2	1985	-29.2	-20.6	-30.0	-28.0	-23.9	-31.9	-63.5	-58.3	-63.5	-65.1	-60.1	-64.4
	1986	-26.0	-18.1	-27.3	-27.6	-23.3	-29.7	-59.0	-54.7	-59.3	-60.6	-53.8	-59.5
	1991	-25.7	-19.9	-29.4	-25.7	-22.6	-30.8	-58.2	-54.4	-58.9	-59.3	-54.3	-59.4
	1992	-25.0	-19.9	-30.7	-27.4	-24.9	-33.7	-59.5	-55.8	-60.4	-60.9	-54.1	-59.8
	TR mean	-27.6	-19.3	-28.6	-27.8	-23.6	-30.8	-61.3	-56.5	-61.4	-62.8	-57.0	-61.9
	PT mean	-25.3	-19.9	-30.1	-26.6	-23.8	-32.3	-58.8	-55.1	-59.6	-60.1	-54.2	-59.6

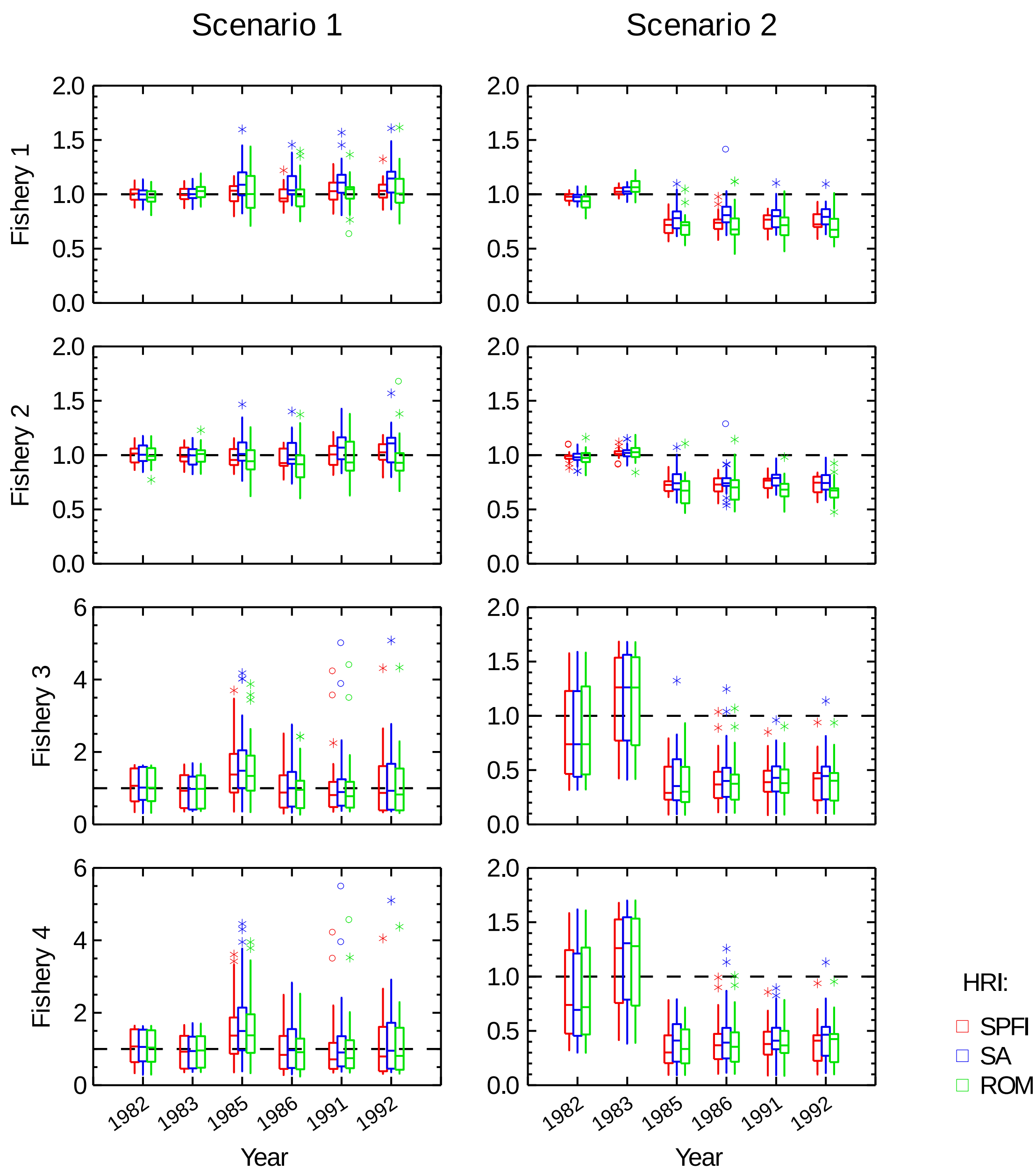


Figure 4-3 Box plot distributions of the SPFI, SA and ROM indices under the two scenarios. Distributions for each fishery for the six selected years are displayed in a row of two panels, one for each scenario. See Figure 4-1 for a description of the box plots. The horizontal line at 1 on the y-axis in each panel indicates the base period average for comparison with any of the distributions and in particular, for those under the harvest rate reductions of scenario 2. The y-scale is the same in all panels except for those for fisheries 3 and 4 under scenario 1. N = 250 per box plot.

The stronger correlation between catch and each metric for fisheries 3 and 4 is also likely due to the fact that the simulation model generated a range of abundances spanning both abundance breakpoints (see section 2.1.1 and Table 2-2) resulting in the application of all three HRI scalars. The range of abundances generated for fisheries 1 and 2 never exceeded the lowest abundance trigger. This resulted in the application of only the first HRI scalar for those fisheries. The effect of the HRI scalars was detectable in the clustering of fishery catches into three distinct groups for fisheries 3 and 4 but into only one for fisheries 1 and 2 (Figure 4-4).

4.2.1.3 Harvest Rate Reductions and Effects on the HR Metrics

Reductions in the HRI scalars following the base period years under scenario 2 (see Table 2-2) did result in approximately the intended reductions in the HR metrics (Tables 4-4 and 4-5, Figure 4-3) in all fisheries. There were interesting differences though, in the average responses of the three metrics. Average reductions observed in the SPFI were closest to the realized reductions in the HRs whereas reductions in the SA were closest to the reductions in the fishery catches (compare mean values given in Tables 4-3 and 4-5 and see Figure 4-5). The reductions in the ROM were greater than in the SPFI or SA for fisheries 1 and 2 but were quite similar to the reductions in the SPFI for fisheries 3 and 4. The average annual value of each metric differed only slightly between fishery 3 and fishery 4 despite the differences in seasonal pattern of catches and contributions of different stocks at a given age to the catch.

Even under scenario 1, there were changes in the average annual HRs, catches and HR metrics relative to the base period average (Figure 4-5). These changes reflected the stochasticity of various input parameters to the simulation program. Generally, the percentage change in the HR metrics followed the same pattern of increases and decreases as observed in the HRs and catches for each fishery. Responses by the three metrics differed somewhat with the SA showing a greater increase with increases in the HR and catch relative to the base period. Conversely, the SPFI and ROM both tended to show greater decreases with decreases in the HR and catch relative to the base period.

4.2.1.4 Characteristics of the Data Contributing to the HR Metrics

The number of stocks and stock-age combinations contributing to calculation of the metrics differed somewhat among the fisheries (Table 4-6). All stocks with tagged fish available for capture in the base period years were observed in fishery 1 (N=13) with 2 or so fewer stocks occurring in the other fisheries. A greater number of stock-age combinations also contributed to the calculation of the metrics for fishery 1 with a relatively similar number contributing in the other fisheries. The percent contribution by age category also varied among the fisheries resulting from the differing stock distributions and the size limits (and PNV values) implemented for each fishery. The number of contributing stocks and stock-age combinations observed in each fishery did not noticeably change following the HR reductions under scenario 2.

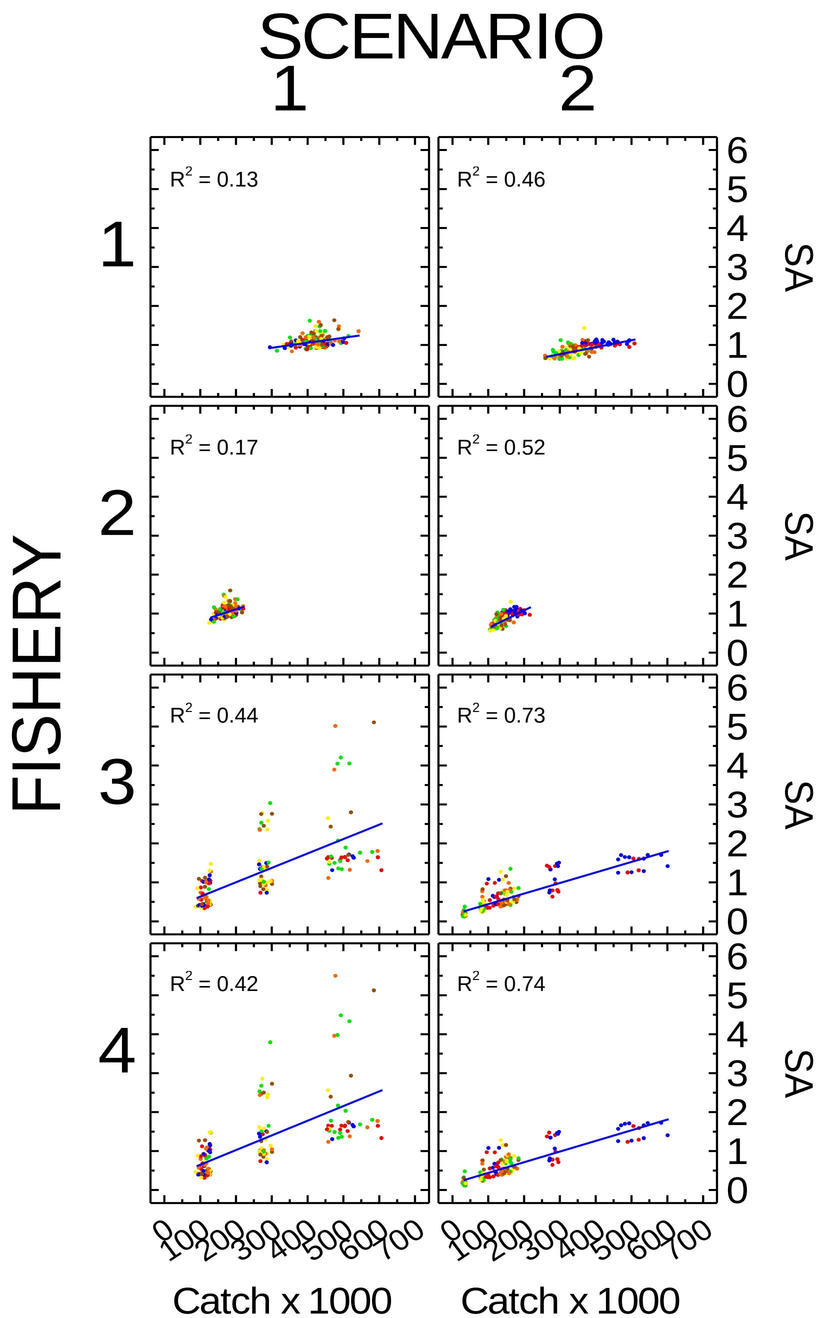


Figure 4-4 Relationship between the SA metric and the true annual catch for each fishery (rows) and scenario (columns). The six years under focus are indicated by a different colour: red=1982, blue=1983, green=1985, yellow=1986, orange=1991, brown=1992). There are 25 values per year and each is the mean of 10 samples. The line from a simple linear regression and the coefficient of determination statistic is shown in each panel.

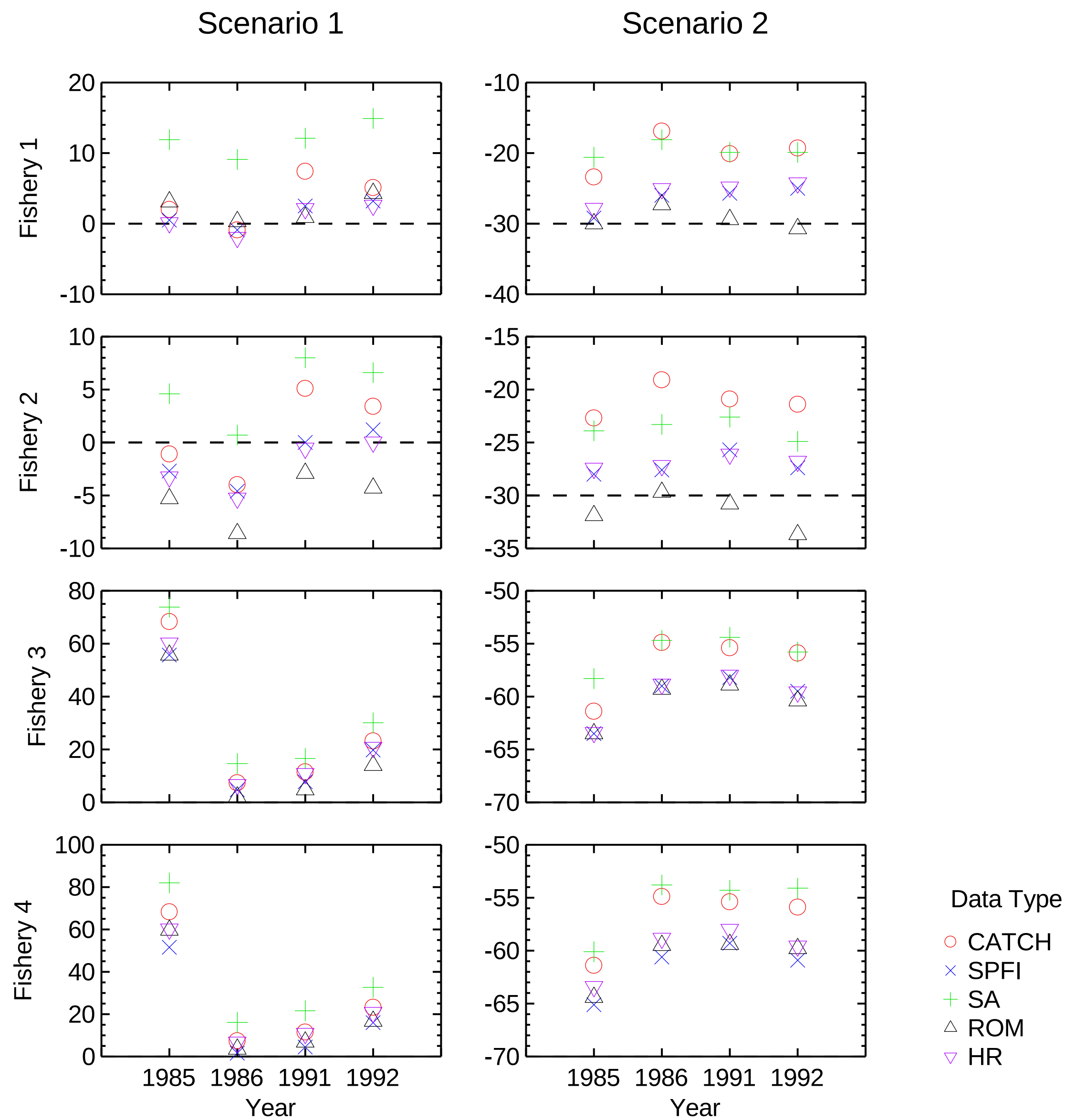


Figure 4-5 Mean percent change by year in the true annual fishery catch, the true HR and the three HR metrics relative to the base period average for each fishery (rows) and scenario (columns). N = 25 for the true catch and HR. N = 250 for the metrics. Note the difference in the y-axis scale among panels. The percentage difference expected on average is 0% under scenario 1 for all fisheries and under scenario 2, it is 30% for fisheries 1 and 2 and 70% for fisheries 3 and 4. The horizontal dashed line can be used for reference in panels where the minimum y-axis value is not equal to the average expected difference.

The number of stocks contributing to the HR metrics calculated from the simulation results was quite similar to the number contributing to the ROM calculated for the actual WCVI troll fishery (Table 4-7). The number of contributing stock-age combinations however, was much lower for the actual WCVI ROM and this was mainly due to a difference in contribution by age 2 fish (Table 4-7). In the simulation results, the majority of stocks contribute at age 2 but in reality, none do. This observation indicates that further tuning of the simulation model through some of the input parameters is needed to better reflect aspects of reality. The possibility is also left open that metric values could differ or show different responses to the harvest rate reductions under more 'realistic' simulation scenarios.

Some investigation of the effects of the number of stocks and stock-age combinations on the calculated values of the metrics was possible in the already existing simulation results. We performed three 'exclusion' experiments from the data generated under each scenario. First, data for two tagged stocks (3, a large stock, and 9, a smaller stock) were excluded from the calculation of the metrics whenever present in the results for a particular iteration and sample (see '2ex' results). Second, data for all stocks caught at age 2 were excluded (see 'no2' results). Finally, the data for the same two stocks and all age 2 fish were excluded in combination (see '2ex_no2' results). The recalculated values of the metrics were then compared with the original values with no exclusions (see 'Allin' results).

The exclusions did result in decreases in the number of stocks and stock-age combinations contributing to the HR metrics (Tables 4-8 and 4-9) with slight differences occurring among fisheries depending on the presence or absence of the two stocks and prevalence of age 2 fish in the fishery catches. A comparison of the average percent difference of the metrics calculated with the three exclusions against the original values without exclusions revealed only a few noticeable patterns. Regardless of the metric, the effects of the exclusions were negligible or small (a change of a few percent) when compared by fishery, year and scenario. Using results from the ROM metric as illustrative of results from all three metrics (Figure 4-6 and Table 4-10), there is no obvious bias due to the exclusions in the distribution of percentage differences under either scenario for fisheries 1 and 2. There is a small but consistent bias, however, under both scenarios in the distributions for the post-base period years for fisheries 3 and 4. The negative bias occurs with each of the exclusions, is slightly greater with the combination exclusion (2ex_no2) and is slightly greater for fishery 4 compared to fishery 3. Whether the HR reductions play any role is unclear.

In summary, the effect of the data removals from the HR metrics is relatively minor at best and increases our confidence in the use of the simulation results to investigate the statistical properties and relative performance of the ROM, SA and SPFI metrics. We also conclude that the simulation program, given its' complexity and simulation of events happening to individual fish (capture in fisheries, maturation, etc.), performed mostly as expected generating data suitable for our objectives in this report. A few unexpected results such as the unrealistically high composition of age 2 fish in the fishery catches and the smaller than intended reduction in the HRs and catches in fisheries 3 and 4 under scenario 2, require future investigation and explanation. These investigations would involve performing additional simulations in which input parameters such as the fishery- and age-specific PNV values and the HRI scalars would be varied. This was not possible in the time frame available for work on this project.

Table 4-6 Mean number of *stocks* and *stock-age* combinations contributing to the calculation of the HR metrics by fishery for scenarios 1 and 2. The mean percentage contribution of the stock-age combinations is also given.

	N stocks		N stock-ages		% Age 2		% Age 3		% Age 4		% Age 5	
Fishery	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
1	13.0	13.0	37.8	38.2	34.2	33.5	29.3	30.2	24.6	24.7	11.9	11.6
2	11.5	11.7	31.4	31.1	35.7	35.3	31.3	32.8	24.5	25.0	8.5	6.9
3	11.2	11.2	31.7	31.5	34.4	33.2	29.4	31.9	24.6	25.1	11.6	9.9
4	11.3	11.3	31.7	31.6	34.6	33.1	29.3	31.5	24.4	25.3	11.7	10.1

Table 4-7 Actual number of *stocks* and *stock-age* combinations and mean percentage contribution by age in the calculation of the ROM for the WCVI AABM fishery. The data are from the annual exploitation rate analysis performed by the CTC in 2007.

Year	N Stocks	Age 2	Age 3	Age 4	Age 5	Total	% Age 2	% Age 3	% Age 4	% Age 5
1979	8	0	5	7	0	12	0.0%	41.7%	58.3%	0.0%
1980	8	0	6	7	0	13	0.0%	46.2%	53.8%	0.0%
1981	12	0	7	10	1	18	0.0%	38.9%	55.6%	5.6%
1982	11	0	8	10	0	18	0.0%	44.4%	55.6%	0.0%
1983	12	0	6	12	1	19	0.0%	31.6%	63.2%	5.3%
1984	10	0	7	8	1	16	0.0%	43.8%	50.0%	6.3%
1985	9	0	6	9	0	15	0.0%	40.0%	60.0%	0.0%
1986	9	0	5	9	0	14	0.0%	35.7%	64.3%	0.0%
1987	10	0	7	7	0	14	0.0%	50.0%	50.0%	0.0%
1988	13	0	7	10	0	17	0.0%	41.2%	58.8%	0.0%
1989	12	0	7	11	1	19	0.0%	36.8%	57.9%	5.3%
1990	12	0	7	12	1	20	0.0%	35.0%	60.0%	5.0%
1991	10	0	6	9	1	16	0.0%	37.5%	56.3%	6.3%
1992	11	0	6	10	1	17	0.0%	35.3%	58.8%	5.9%
1993	8	0	7	8	1	16	0.0%	43.8%	50.0%	6.3%
1994	9	0	4	9	1	14	0.0%	28.6%	64.3%	7.1%
1995	8	0	5	6	1	12	0.0%	41.7%	50.0%	8.3%
1996	11	0	8	8	0	16	0.0%	50.0%	50.0%	0.0%
1997	11	0	6	10	0	16	0.0%	37.5%	62.5%	0.0%
1998	8	0	4	7	0	11	0.0%	36.4%	63.6%	0.0%
1999	10	0	6	6	1	13	0.0%	46.2%	46.2%	7.7%
2000	8	0	5	8	0	13	0.0%	38.5%	61.5%	0.0%
2001	11	0	8	9	0	17	0.0%	47.1%	52.9%	0.0%
2002	11	0	8	11	0	19	0.0%	42.1%	57.9%	0.0%
2003	12	0	7	12	0	19	0.0%	36.8%	63.2%	0.0%
2004	11	0	8	11	1	20	0.0%	40.0%	55.0%	5.0%
2005	12	0	8	12	0	20	0.0%	40.0%	60.0%	0.0%
Average	10.2	0.0	6.4	9.2	0.5	16.1	0.0%	39.9%	57.3%	2.8%

Table 4-8 Mean number and standard deviation of stocks contributing to four variants of the HR metrics. The maximum possible is 13 (tags for 3 of the 16 model stocks were not available for recovery during the base period). The variants are calculated by exclusion of certain data: 1) 'no2' reflects exclusion of all age 2 data; 2) '2ex' reflects exclusion of data for two stocks, 3 and 9; and 3) '2ex_ no2' combines both of the preceding exclusions. 'Allin' reflects the original results with no exclusions. N = 250.

		Allin		no2		2ex		2ex_no2	
Scenario	**Fishery**	**N**	**SD**	**N**	**SD**	**N**	**SD**	**N**	**SD**
1	1	13.0	0.2	11.6	1.0	12.0	0.2	11.4	0.8
	2	11.5	0.9	10.6	1.3	10.5	0.9	9.7	1.2
	3	11.2	1.0	10.1	1.7	10.2	1.0	9.2	1.6
	4	11.3	0.9	10.1	1.7	10.3	0.9	9.1	1.7
2	1	13.0	0.2	11.9	0.8	12.0	0.2	11.6	0.6
	2	11.7	0.7	11.0	1.2	10.7	0.7	10.1	1.0
	3	11.2	0.8	10.6	1.2	10.2	0.8	9.6	1.2
	4	11.3	0.8	10.6	1.2	10.3	0.8	9.6	1.2

Table 4-9 Mean number and standard deviation of stock-age combinations contributing to the four HR metric variants. See the preceding table for description of the variants. N = 250.

		Allin		no2		2ex		2ex_no2	
Scenario	**Fishery**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
1	1	37.8	3.7	25.0	3.6	36.6	3.6	24.8	3.6
	2	31.4	4.6	20.4	4.2	29.2	4.2	19.1	3.8
	3	31.7	6.3	21.1	5.9	28.2	5.9	18.7	5.4
	4	31.7	6.4	21.0	5.9	28.3	5.9	18.6	5.4
2	1	38.2	2.7	25.5	2.7	36.9	2.6	25.2	2.5
	2	31.1	3.9	20.2	3.6	28.9	3.6	19.1	3.3
	3	31.5	4.8	21.1	4.0	28.2	4.6	18.8	3.8
	4	31.6	4.7	21.3	4.0	28.4	4.5	19.1	3.8

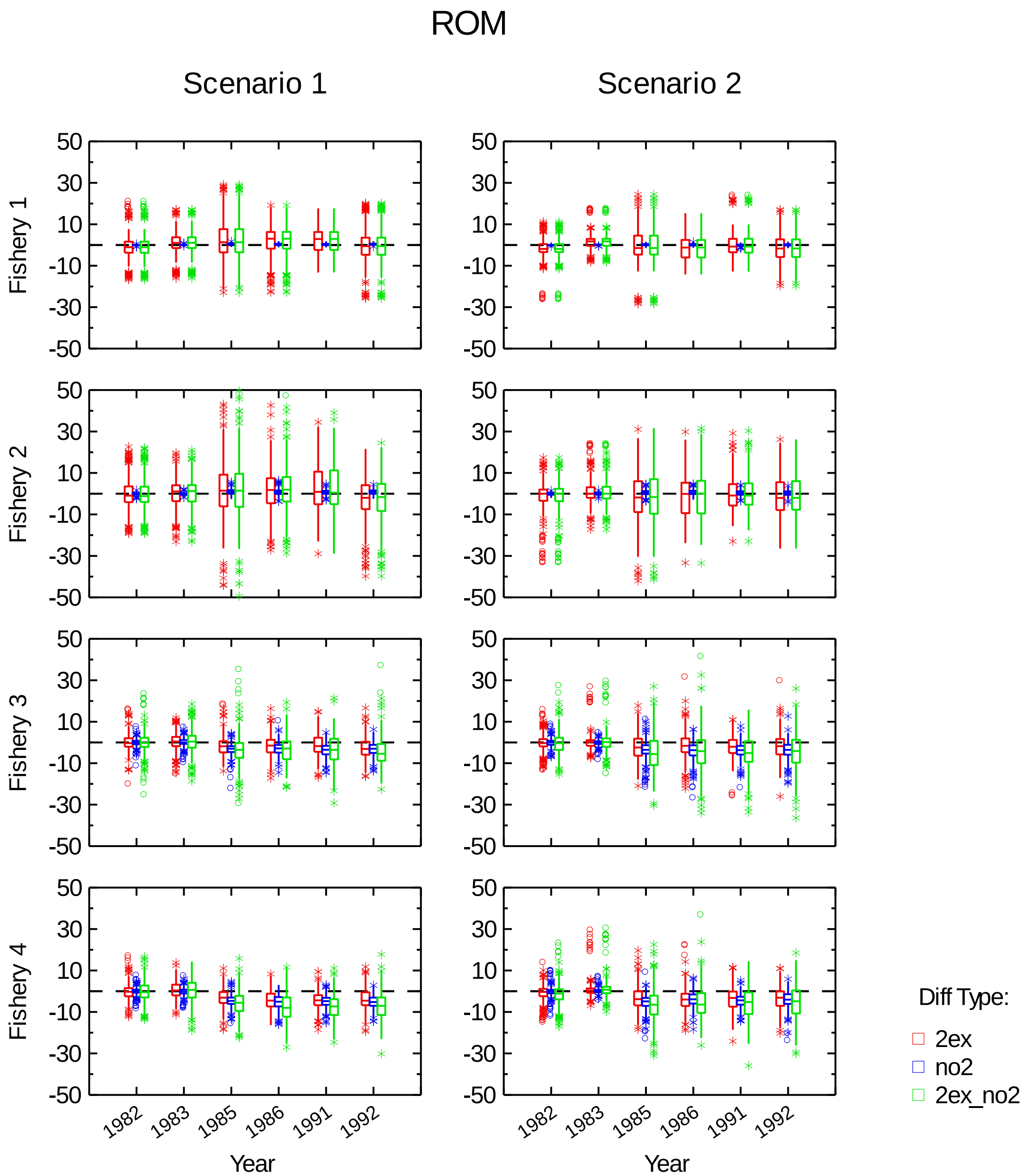


Figure 4-6 Box plot distributions by scenario and fishery of percent difference between the ROM metric calculated with all stock-age combinations exceeding the minimum criterion (>35 average CWT recoveries in the base period years) and three other ROM variants, each based on an exclusion of data. The dashed horizontal line indicates no difference. N = 250 for each box plot.

Table 4-10 Mean percent difference between the ROM metric based on all stock-age combinations and three variants. The metric is based on completed broods only. See the text and Table 4-8 caption for a description of the variants. N = 250.

		Fishery 1			Fishery 2			Fishery 3			Fishery 4		
Scenario	Year	no2	2ex	2ex_no2	no2	2ex	2ex_no2	no2	2ex	2ex_no2	no2	2ex	2ex_no2
1	1982	-0.96	-0.10	-0.97	0.09	0.01	0.02	-0.15	-0.08	-0.25	-0.30	0.01	-0.28
	1983	0.98	0.09	0.98	0.19	-0.03	0.27	0.11	0.07	0.21	0.52	-0.21	0.33
	1985	2.01	0.54	2.01	1.79	0.96	2.24	-1.80	-3.36	-3.92	-3.05	-4.68	-5.75
	1986	1.82	0.33	1.82	2.14	0.79	2.66	-1.66	-2.98	-3.21	-4.36	-5.16	-7.62
	1991	1.89	0.23	1.89	2.67	0.67	2.81	-1.30	-3.72	-3.64	-4.61	-4.91	-7.59
	1992	-0.56	0.38	-0.56	-2.86	0.77	-2.60	-2.65	-3.08	-4.47	-3.85	-5.11	-7.20
2	1982	-2.24	-0.13	-2.24	-1.58	-0.05	-1.58	-0.11	-0.09	-0.24	-0.99	-0.17	-1.35
	1983	1.70	0.09	1.70	1.03	0.03	1.03	0.42	-0.12	0.39	1.10	0.16	1.46
	1985	-0.59	0.14	-0.60	-1.49	0.53	-1.13	-1.99	-3.68	-4.47	-3.27	-5.23	-6.36
	1986	-1.14	0.10	-1.15	-1.08	0.60	-0.75	-1.41	-4.13	-4.32	-3.92	-3.85	-5.38
	1991	-0.22	-0.03	-0.23	-0.07	0.38	0.25	-1.95	-4.02	-4.56	-3.43	-4.68	-5.54
	1992	-1.99	0.04	-2.00	-0.98	0.31	-0.87	-1.71	-4.05	-4.54	-3.56	-4.07	-5.26

4.2.2 Stock Indices

Stock indices are the individual stock- and age-specific indices calculated as the annual ER divided by its' corresponding average during a base period ($cyERI_{f,y,s,a}$ in equation 4-3). At most, the simulation model was designed to yield 250 stock indices for each stock per year (25 iterations x 10 samples (Table 4-11). Some stocks had fewer than 250 stock indices when the criteria were not met in the base-period years which meant that stock indices could not be calculated in subsequent years if CWTs were recovered. The criteria were not met for the base period years when ERs were estimated as 0 or when fewer than 35 estimated CWTs were harvested in fisheries. These situations can arise from factors such as low stock distributions in a fishery, a low proportion of the cohort being vulnerable by age and fishery, small CWT cohort sizes, and low sampling rates in fisheries. It can also arise from variation in these processes as evident from the absence of stock indices for stock 9 in scenarios 1 and 2 (Figure 4-7 and Figure 4-8): stock 9 had small cohort sizes on average (Figure 3-1). For stocks meeting the base period criteria, stock indices were estimated in all subsequent years within an iteration and sample, even if circumstances of small cohort sizes, low sampling rates in fisheries, or variations in growth reduce the proportion of the cohort vulnerable to fisheries and resulted in no CWTs being recovered. In these situations, the number of stock indices followed a repeating pattern across years, and if there were 149 unique iteration *x* sample estimates of ERs in the base period, then there can be only 149 stock indices in each year after the base period (e.g. stock 3, age 5 in Table 4-11).

The frequency and distribution of stock indices was examined for any unusual patterns, which may indicate that the simulation model was not performing as it was intended. There were no stock indices for stocks 2 or 5 because these stocks were not tagged, whereas stock 9 was tagged, but the base period CWT criteria were not met for fishery 3 to calculate stock indices in subsequent years. In fishery 3, there were no stock indices for stock 1 because its distribution did not include fishery 3. Across ages in a fishery and scenario, the largest number of stock indices were generally for age 2, followed by ages 3, 4, and 5 in decreasing frequency. However exceptions can occur when vulnerability increases with age, due to age-specific variation in stock distribution or growth for example, or when random variation contributed to base period criteria being met more often for older ages. For example, stock 4 has a larger number of stock indices at age 5 than age 4, and age 4 than age 3 in scenario 1, fishery 3 (Table 4-11). The distribution of stock indices varied among stocks within a year (Figure 4-7 and Figure 4-8).

Table 4-11. Frequency of stock indices based on complete tag data, by age and stock, contributing to fishery 3 in scenario 1.

	Age				
Stock	**2**	**3**	**4**	**5**	**Total**
3	244	245	219	149	857
4	165	100	106	107	478
6	158	127	47	0	332
7	250	250	250	161	911
8	241	213	211	155	820
10	187	148	49	0	384
11	220	220	196	156	792
12	250	250	250	61	811
13	241	201	211	77	730
14	250	240	166	0	656
15	250	185	156	77	668
16	185	141	104	49	479
Total	2641	2320	1965	992	7918

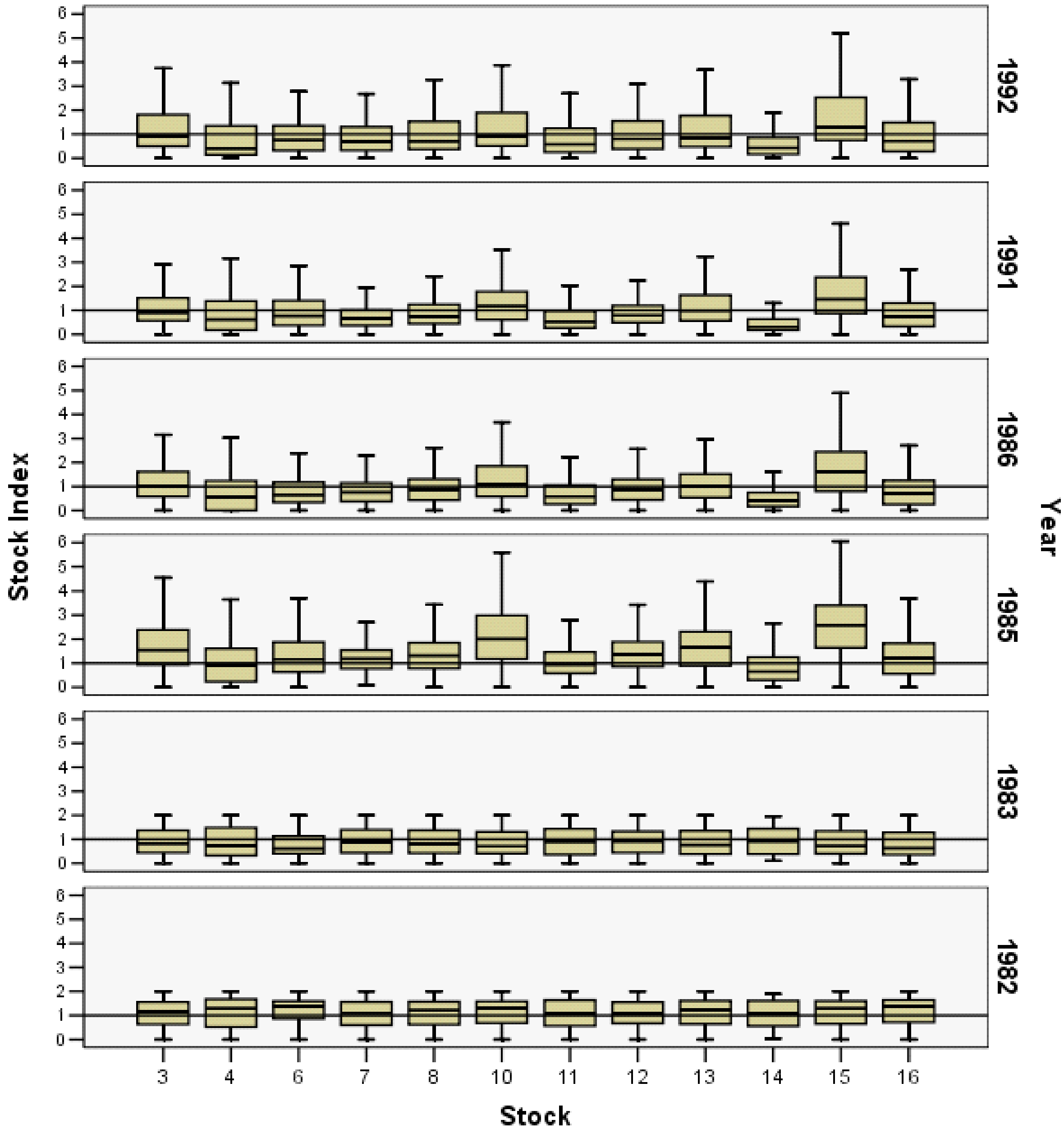


Figure 4-7. Box plots of stock indices based on complete tag data for fishery 3 in scenario 1 by stock and year. Reference line at 1 identifies the average base period stock index.

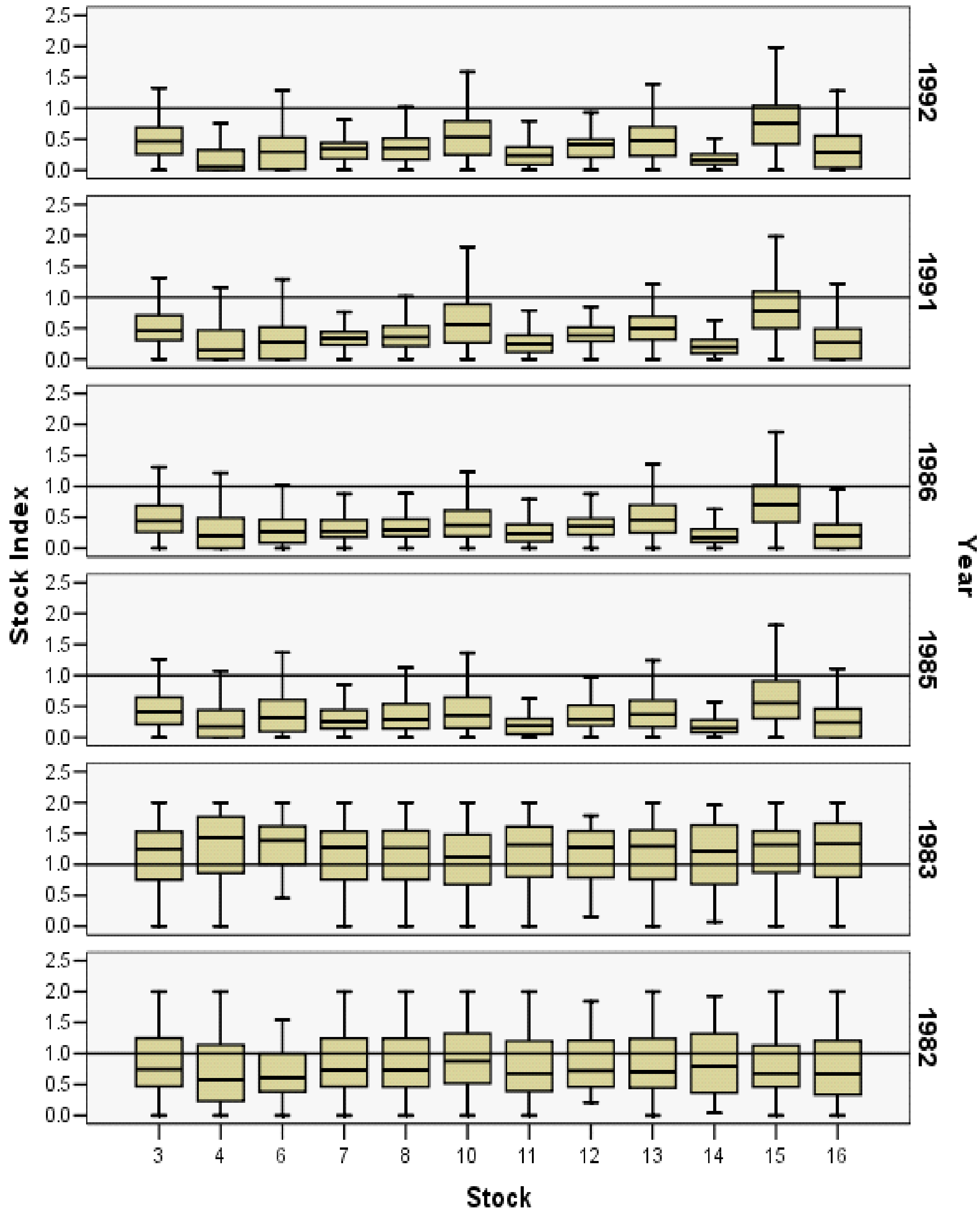


Figure 4-8. Box plots of stock indices based on complete tag data for fishery 3 in scenario 2 by stock and year. Reference line at 1 identifies the average base period stock index.

An important simulation model design distinction between scenarios 1 and 2 was the harvest rate reductions that occurred after the base period for scenario 2. For both scenarios, the base period stock indices were centered around values of 1 as intended, and the distributions were multimodal and widely distributed for fisheries 3 and 4, but unimodal and more narrowly distributed for fisheries 1 and 2 (Figure 4-9). The mechanisms producing the multimodal distributions for fisheries 3 and 4 are unclear. Among stock indices the harvest rate reductions in fishery 3 were evident after the base period for scenario 2 when compared to scenario 1 for all stocks combined (Figure 4-10) and individual stocks (Figure 4-7 and Figure 4-8), as they were designed to.

To examine the influence of a stock without base period tagging, the distributions of stock indices in scenarios 1 and 2 were examined with and without stock 3. However, only minor variations were apparent for scenarios 1 and 2 (Figure 4-11 and Figure 4-12). When the cumulative frequency distributions were compared with and without stock indices for stock 3 for fishery 3 by year, no significant differences were found over the 6 years for both scenarios (12 Kolmogorov-Smirnov tests: Bonferoni adjusted P critical value = 0.05/12 = 0.004; all $P \geq 0.067$). Also, no significant differences were detected in the distributions for fishery 4 in both scenarios (12 Kolmogorov-Smirnov tests: Bonferoni adjusted P critical value = 0.05/12 = 0.004; all $P > 0.022$). The small influence of this stock was likely affected by the similarity of the distribution of stock indices among stocks within a year, as illustrated in Figure 4-7 and Figure 4-8.

Different temporal catch patterns between fishery 3 and 4 produced significantly different stock index distributions in some years following the base period for both scenarios (Figure 4-13 and Figure 4-14). In scenario 1, the distributions were significantly different in 1985 (Kolmogorov-Smirnov test; $P<0.001$), but not in the other years (five Kolmogorov-Smirnov tests: all $P \geq 0.007$). In scenario 2, the distributions were significantly different in 1991 (Kolmogorov-Smirnov test; $P = 0.001$), but not in the other years (five Kolmogorov-Smirnov tests: all $P \geq 0.010$).

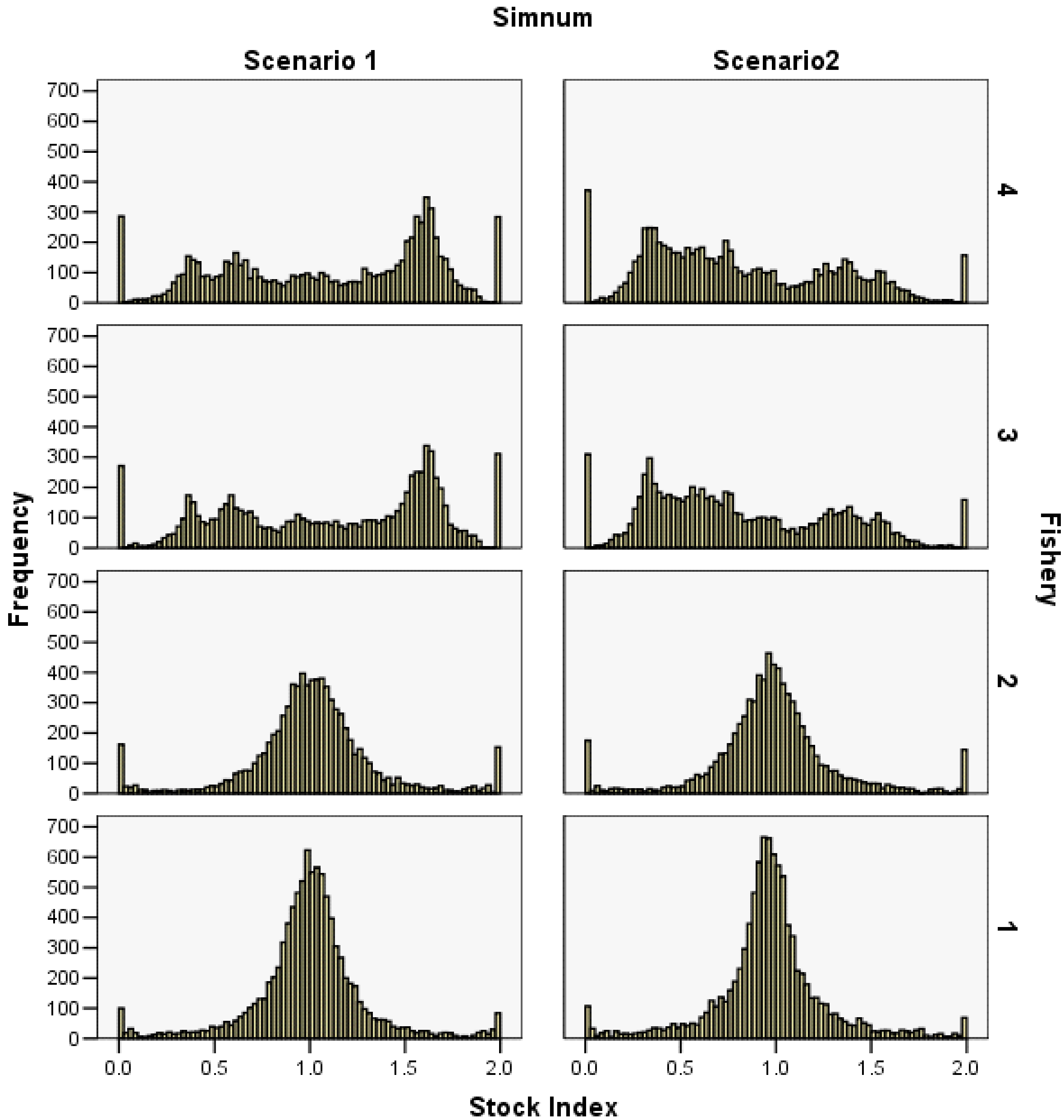


Figure 4-9. Frequency distribution of stock indices based on complete tag data for scenarios 1 and 2 for all stocks, including stock 3, for fisheries 1 to 4 in 1982.

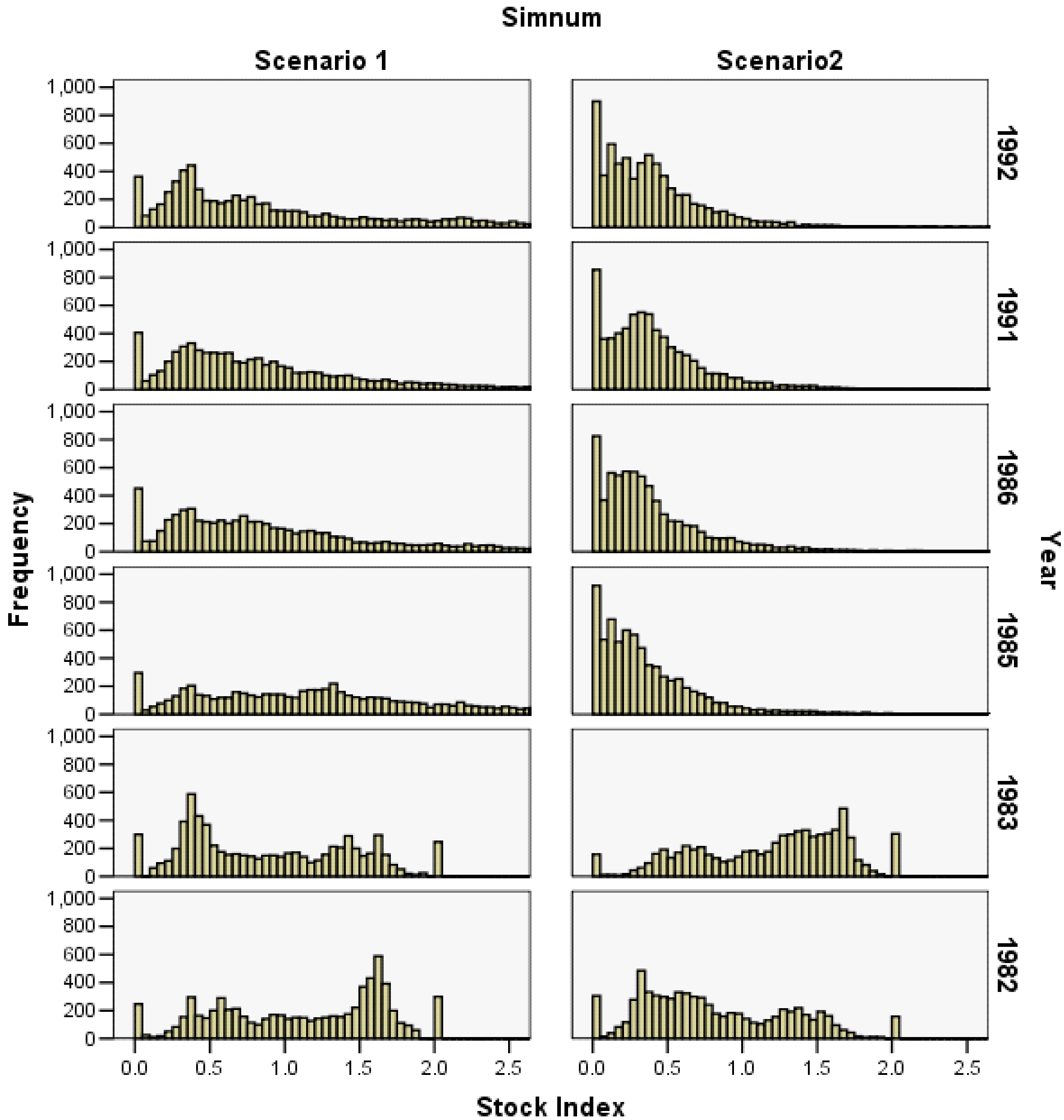


Figure 4-10. Frequency distribution of stock indices based on complete tag data for fishery 3 for scenarios 1 and 2, excluding stock 3.

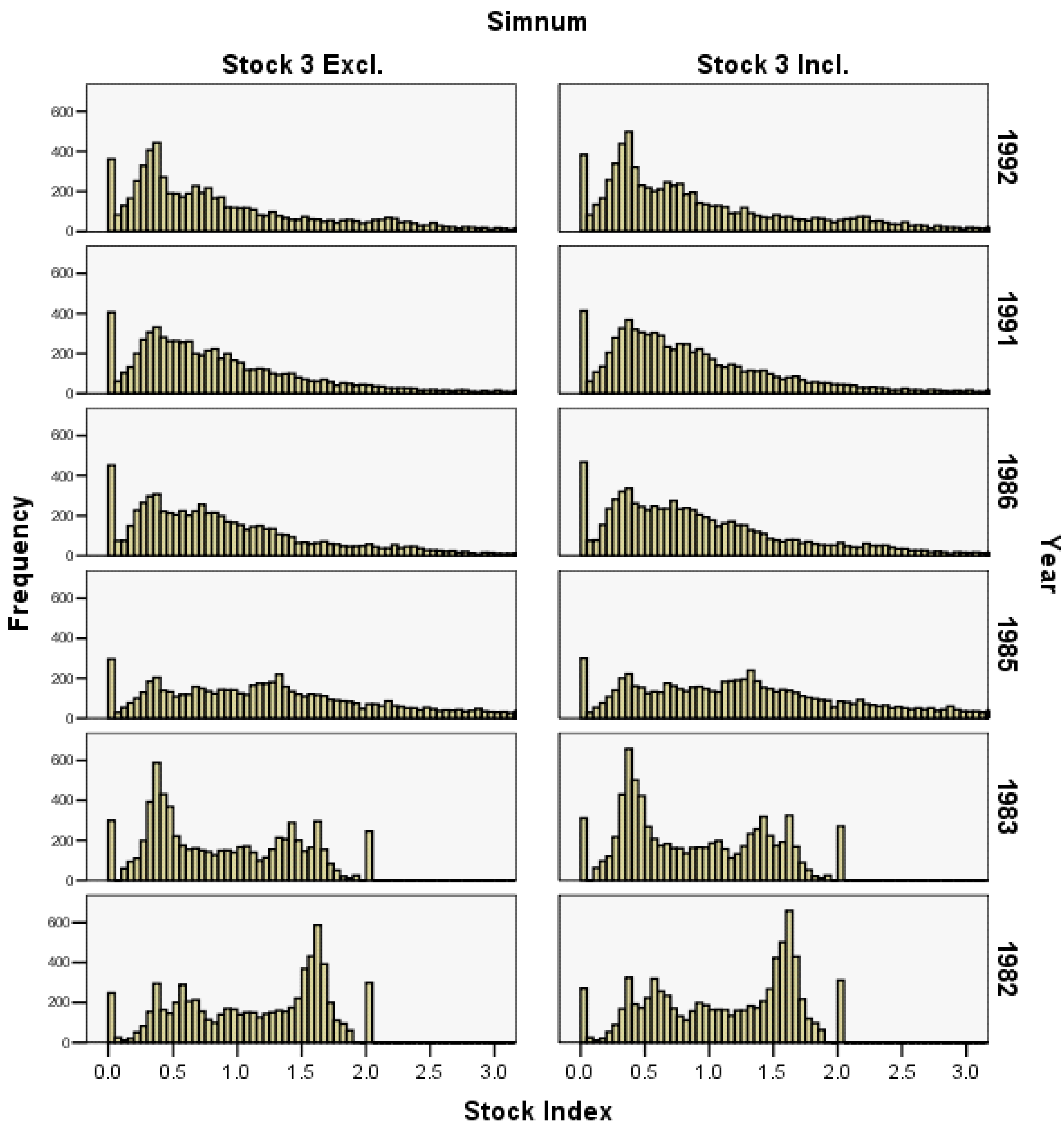


Figure 4-11. Frequency distribution of stock indices based on complete tag data for fishery 3 in scenario 1 including and excluding stock 3.

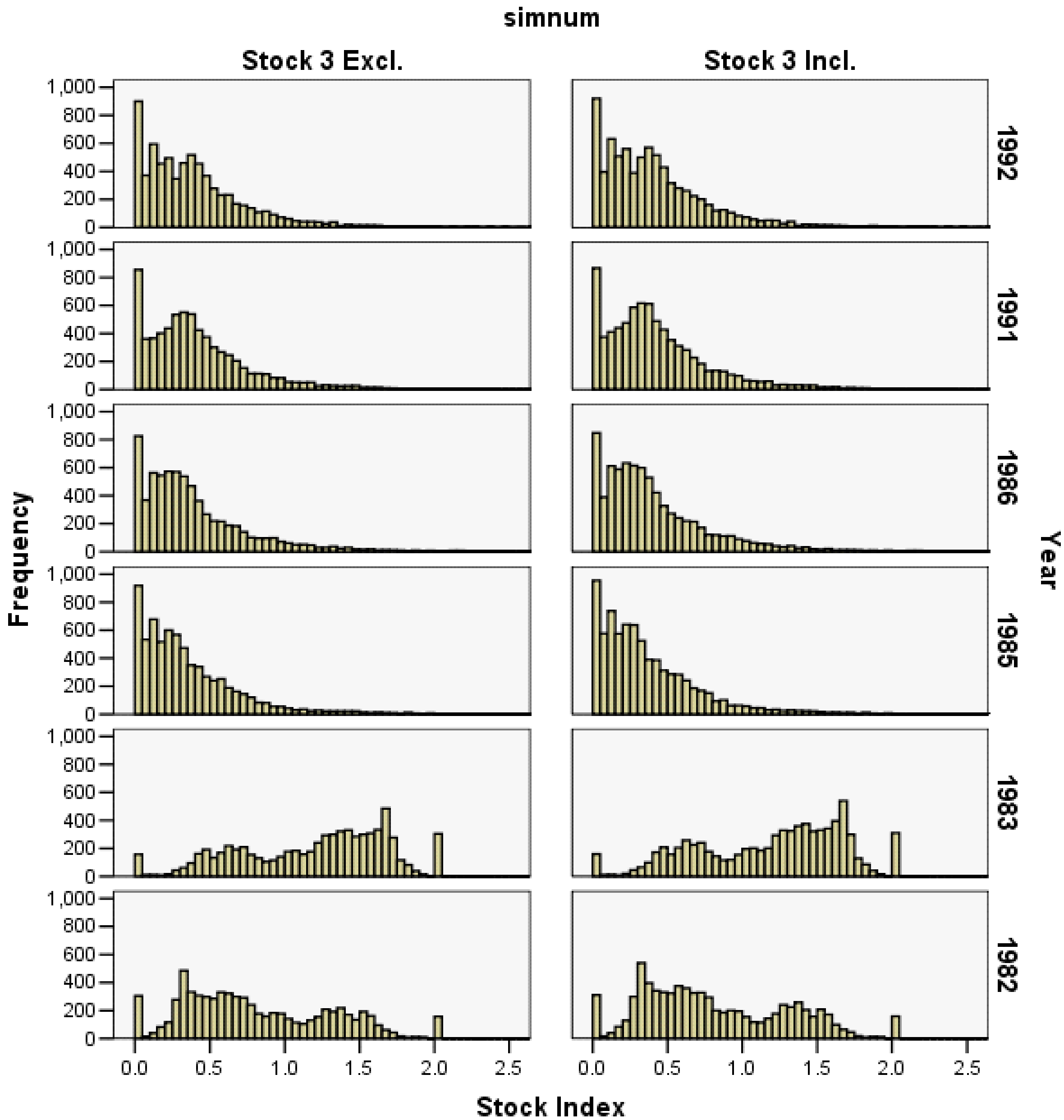


Figure 4-12. Frequency distribution of stock indices based on complete tag data for fishery 3 for scenario 2 including and excluding stock 3.

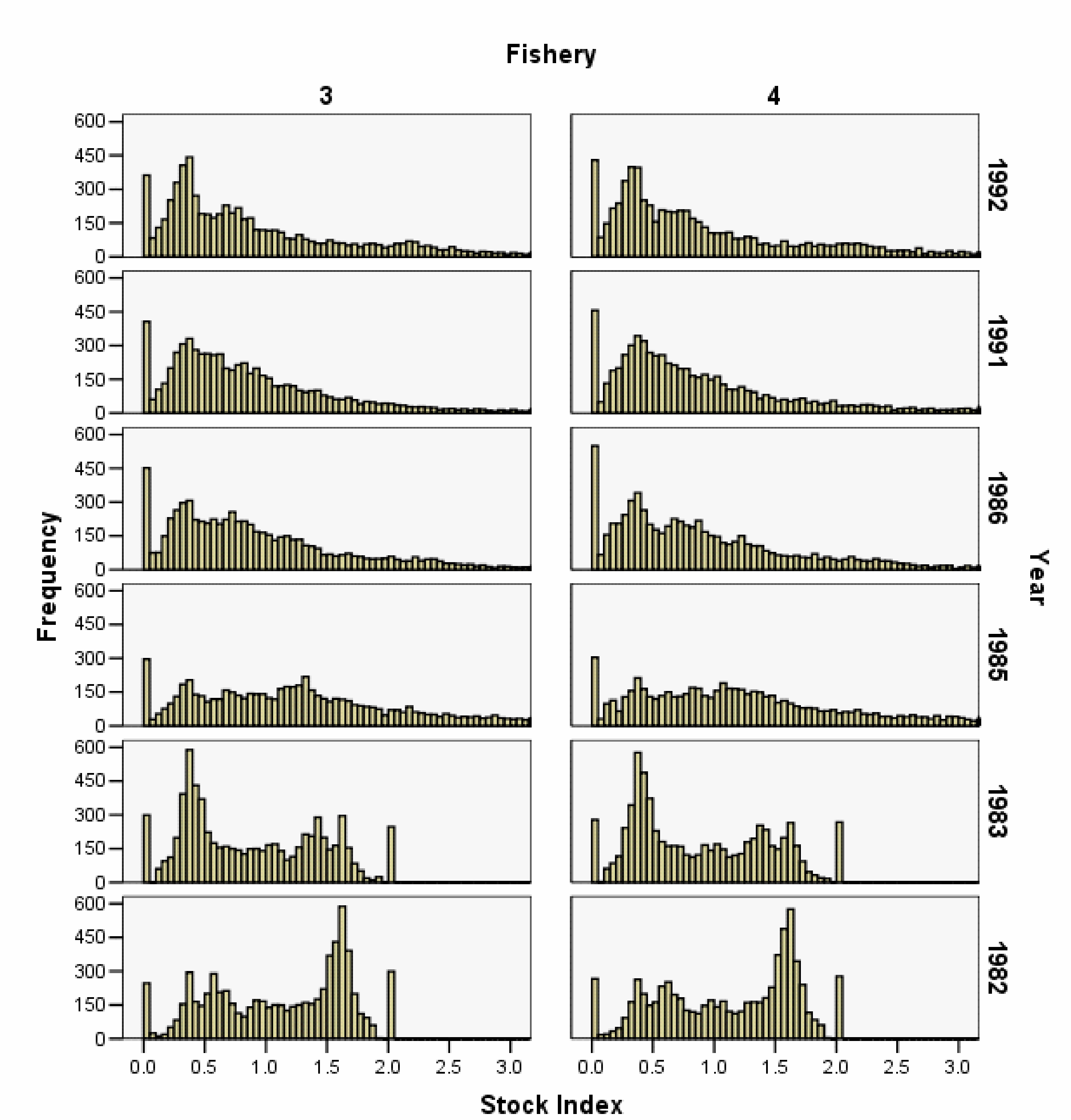


Figure 4-13. Frequency distribution of stock indices based on complete tag data for all stocks in scenario 1 for fisheries 3 and 4 by year.

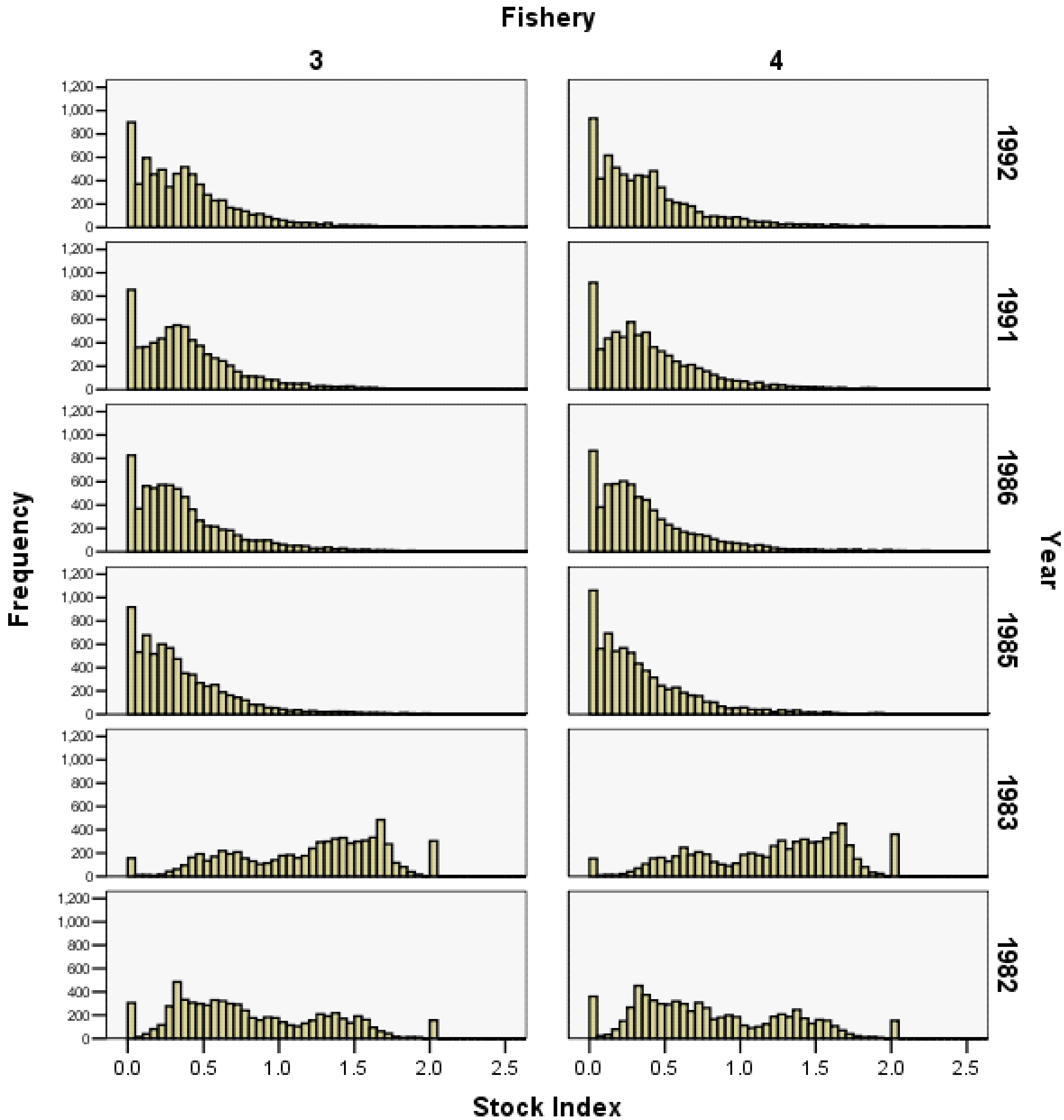


Figure 4-14. Frequency distribution of stock indices based on complete tag data for all stocks in scenario 2 for fisheries 3 and 4 by year.

4.2.2.1 Estimation Errors for individual stock indices

To further examine the performance of the simulation model, several comparisons were made between stock indices based on complete tag data (complete estimates) and versions of stock indices estimated before tag data for all ages in a brood were available (incomplete estimates). The accuracy of the incomplete stock indices increases as a brood matures to completion because more CWT data are collected at later ages to reconstruct the initial CWT cohort size, and this pattern was observed in both scenarios for all stocks (Figure 4-15). In Figure 4-15, the stock indices have a much wider distribution of absolute errors, estimated as the incomplete index minus the complete index, at the first incomplete index for age 2. The distribution of errors becomes narrower for the age 2 indices as the brood becomes more complete for the second incomplete age 2 index, and third incomplete age 2 index. Also, the distribution of absolute errors is narrower for older ages than younger ages because the cohort sizes are estimated more accurately at an older age as a larger proportion of the cohort has matured. The distributions of errors for the incomplete indices were examined among stocks for systematic biases or skewness, and no unusual patterns were observed. The error distributions varied among stocks, and were generally centered on 0 for ages 2 and 3 (Figure 4-16 and Figure 4-17).

When incomplete stock indices were plotted against completed stock indices, nearly all paired observations were along the 1:1 equality line (Figure 4-18). However, some stocks had more variation around the 1:1 line than others, such as stocks 4, 13, and 15 in fishery 3 (Figure 4-18), which was most likely influenced by tagged cohort size, stock distribution, and proportion of the cohort vulnerable to the fishery. Further, stock 14 had extremely large variation in the complete and incomplete stock indices at age 2 for fishery 1 and fishery 2 in both scenarios, and the mechanisms contributing to this unusual pattern were unclear (Figure 4-19).

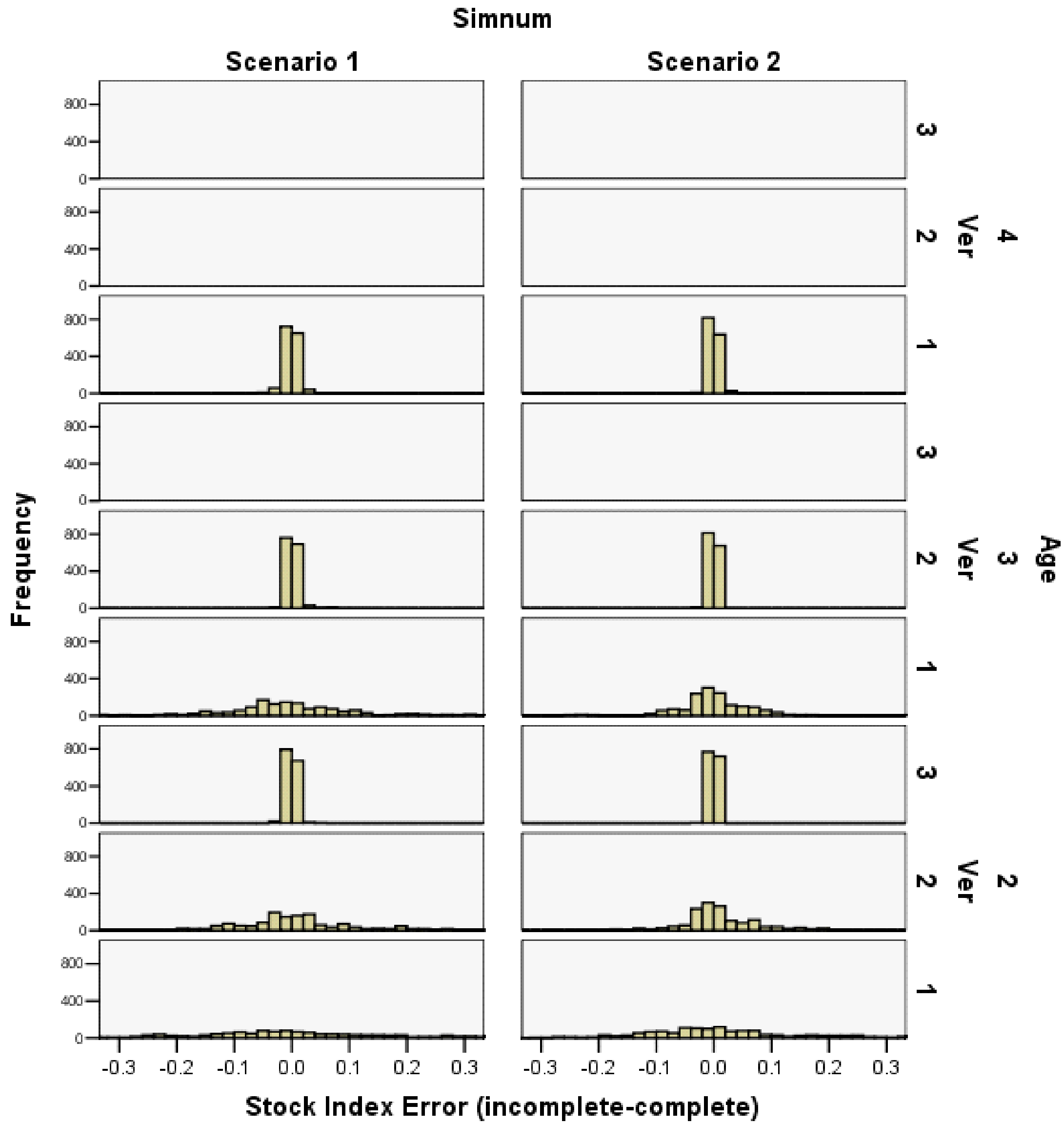


Figure 4-15. Frequency distribution of errors in stock indices for the first, second, and third incomplete versions (Ver) of stock 7 in fishery 3 for scenarios 1 and 2.

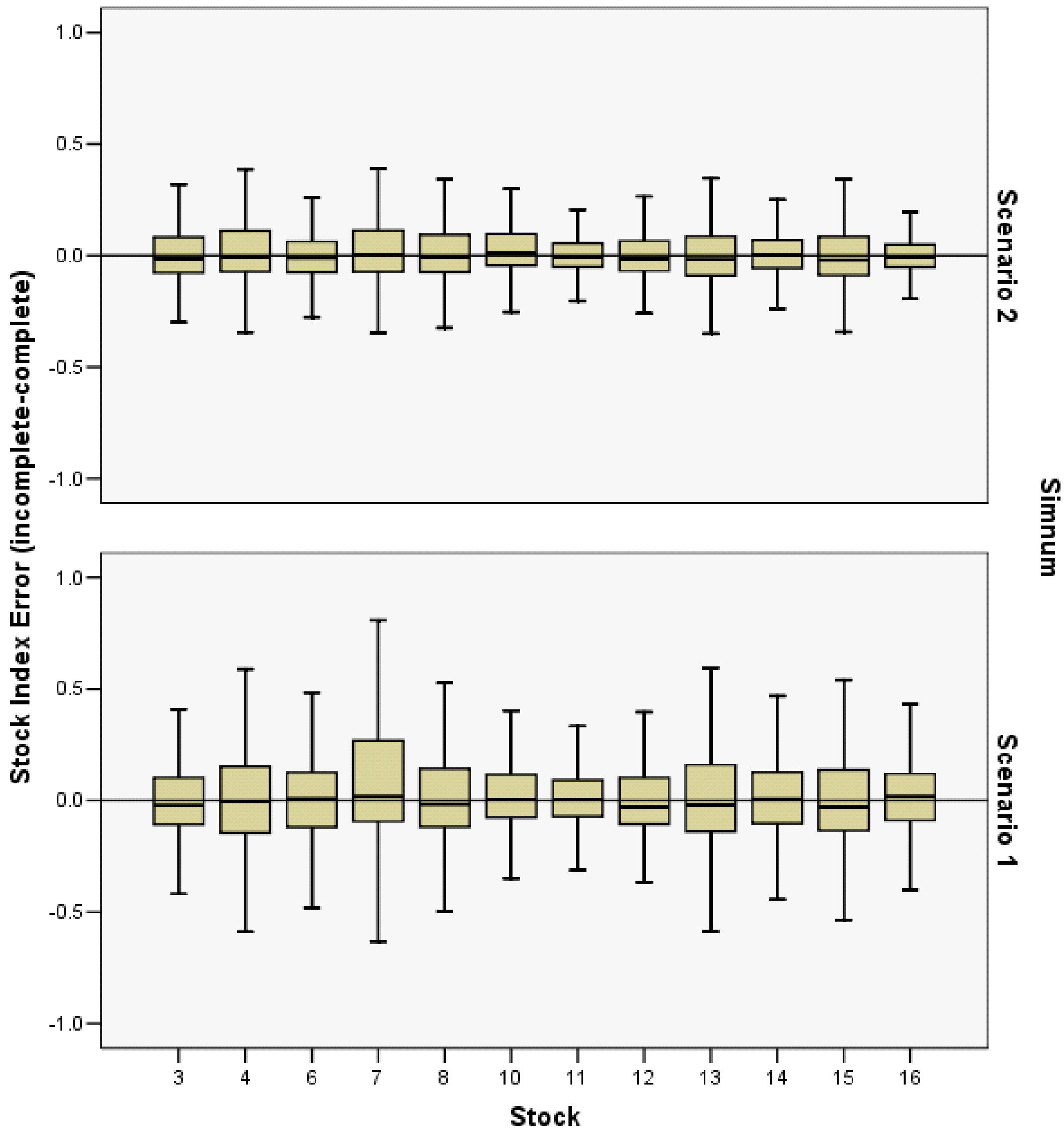


Figure 4-16. Box plots of errors in the first incomplete age 2 stock indices for all stocks in fishery 3 for scenarios 1 and 2, with a reference line at 0.

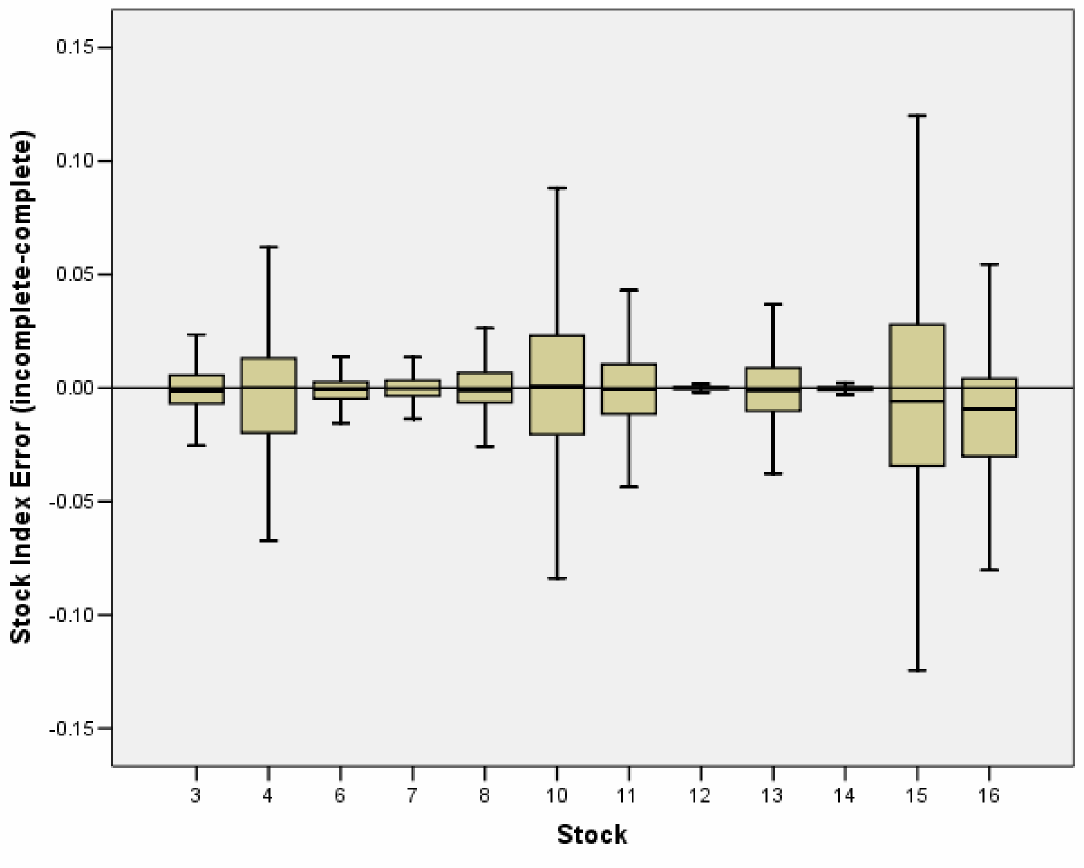


Figure 4-17. Box plots of errors in the second incomplete age 3 stock indices for all stocks in fishery 3 for scenario 1, with a reference line at 0.

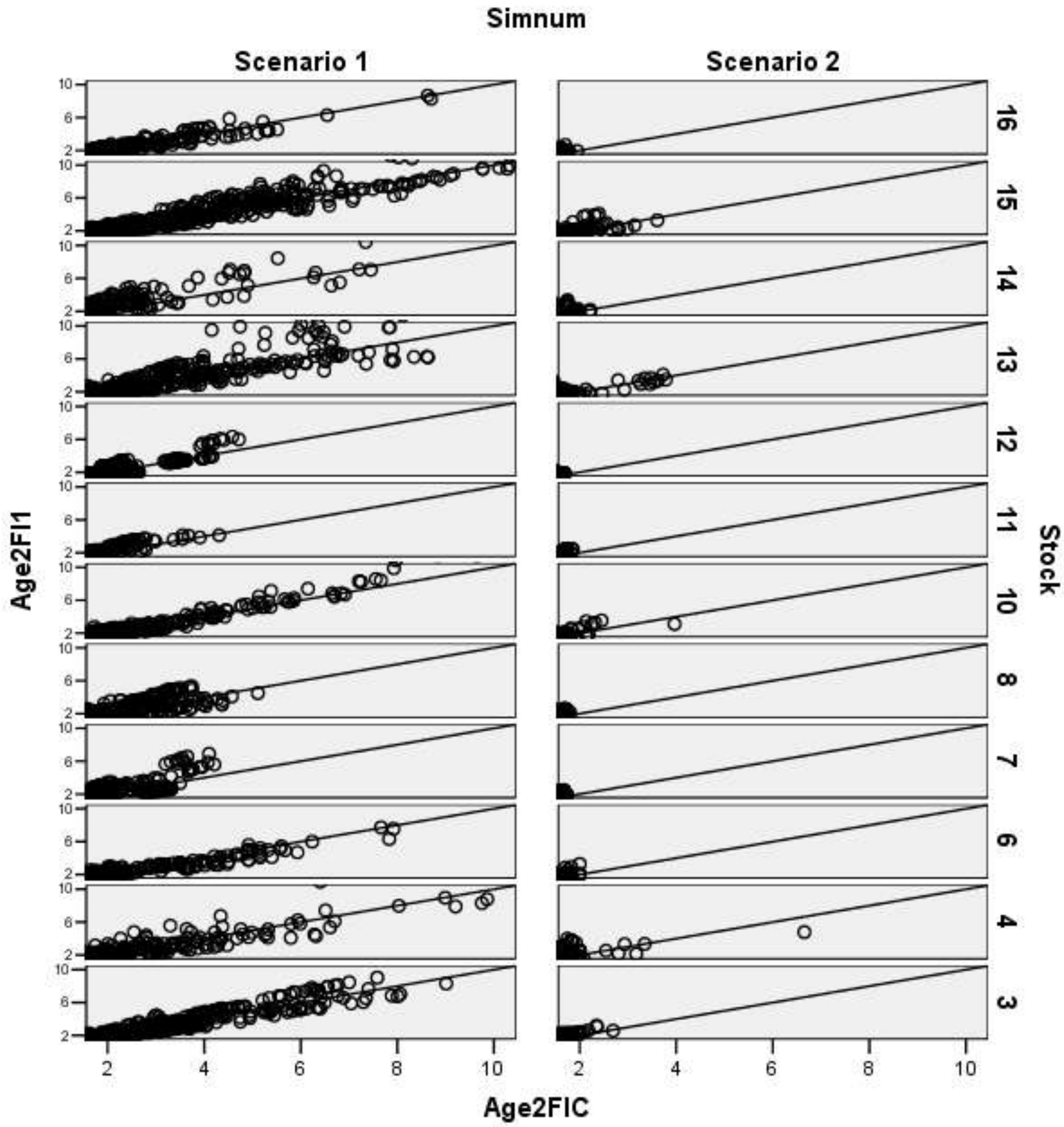


Figure 4-18. Scatter plot of the first incomplete age 2 stock index (Age2FI1) against the complete age 2 stock indices (Age2FIC) by stock in fishery 3 for scenarios 1 and 2, with 1:1 equality line. Axes scales were reduced to illustrate variability among stocks.

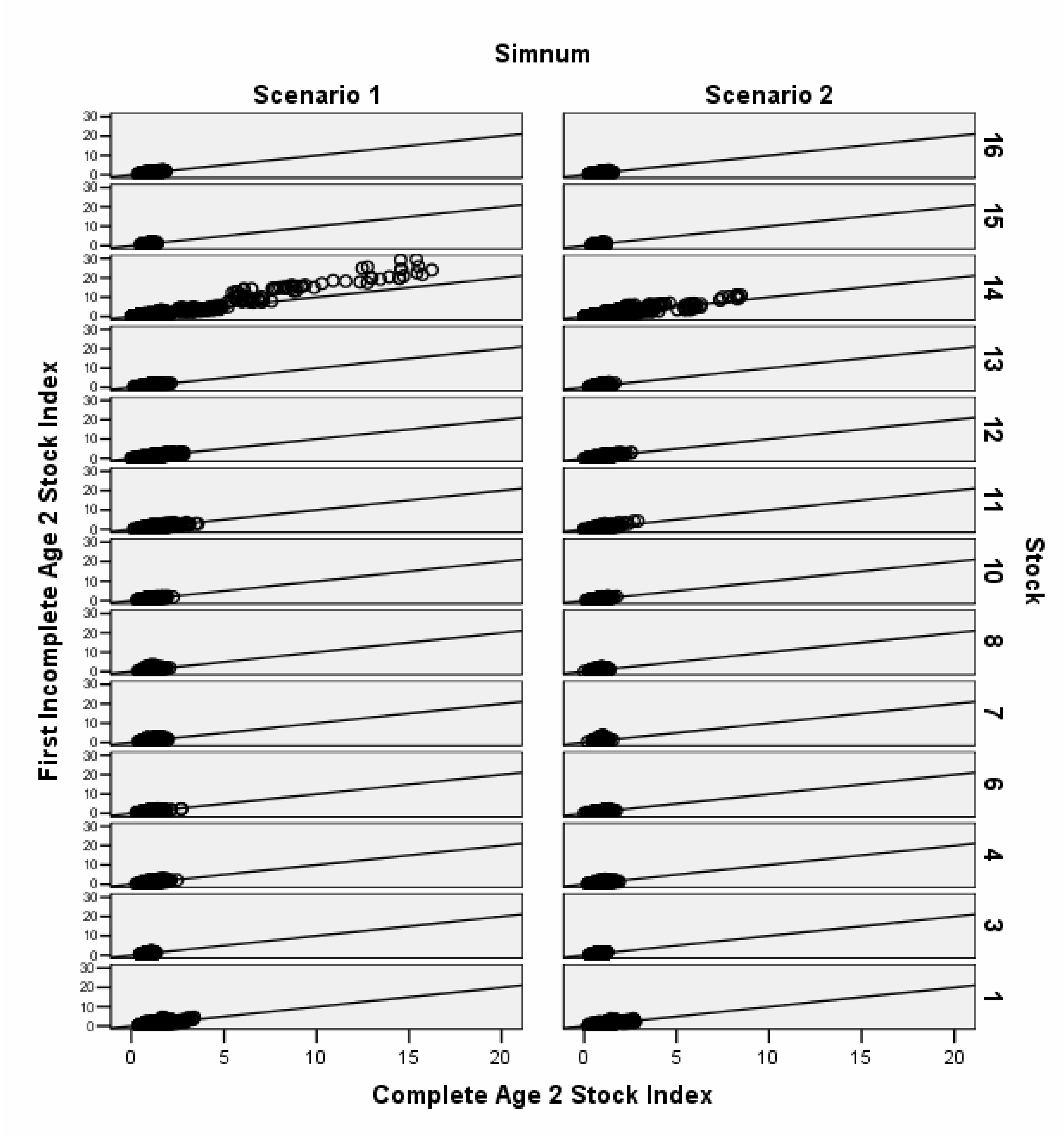


Figure 4-19. Scatter plot of the first incomplete age 2 stock indices against the complete age 2 stock indices for stock 14 in fishery 1 for scenarios 1 and 2, with 1:1 equality line.

4.2.2.2 Estimation Errors for HRIs calculated by ROM and SA methods

To further examine the performance of the simulation model, comparisons were made between complete HRIs and each version of incomplete HRIs calculated by the ROM and SA methods. The accuracy of the SA and ROM HRIs increase as broods mature to completion because the additional CWT data from the older ages improves the estimate of the initial CWT cohort sizes for all the stocks and ages contributing to the HRI. This pattern was observed in both scenarios for all fisheries (Figure 4-20 and Figure 4-21). For both ROM and SA HRIs, there is a pattern of the incomplete HRI being biased high (overestimated) compared to the completed HRI, which was consistent with the pattern observed for the actual WCVI HRI (CTC Small Group , 2007). The pattern is due to the overestimation of exploitation rates for incomplete broods, and the extent of overestimation decreases as broods become more complete as demonstrated in Table 3-4 and Figure 3-7.

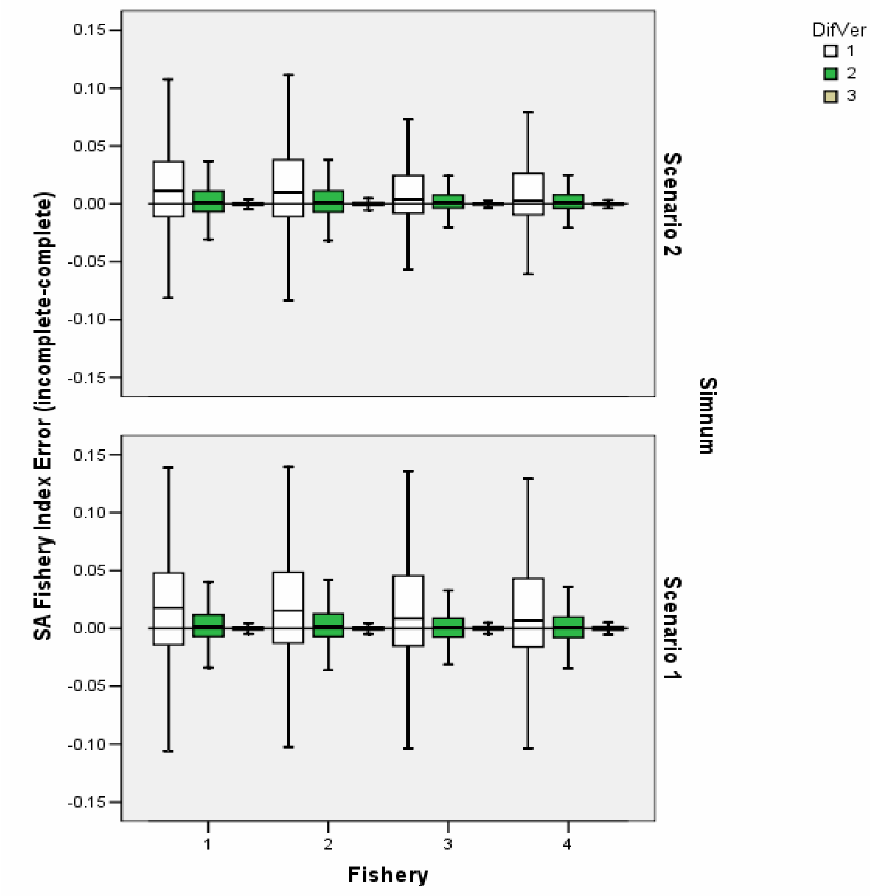


Figure 4-20. Box plots of the errors in the first, second and third incomplete version (DifVer) of the SA HRI for fisheries 1 to 4 across all iterations, years, and samples for scenarios 1 and 2, with a reference line at 0.

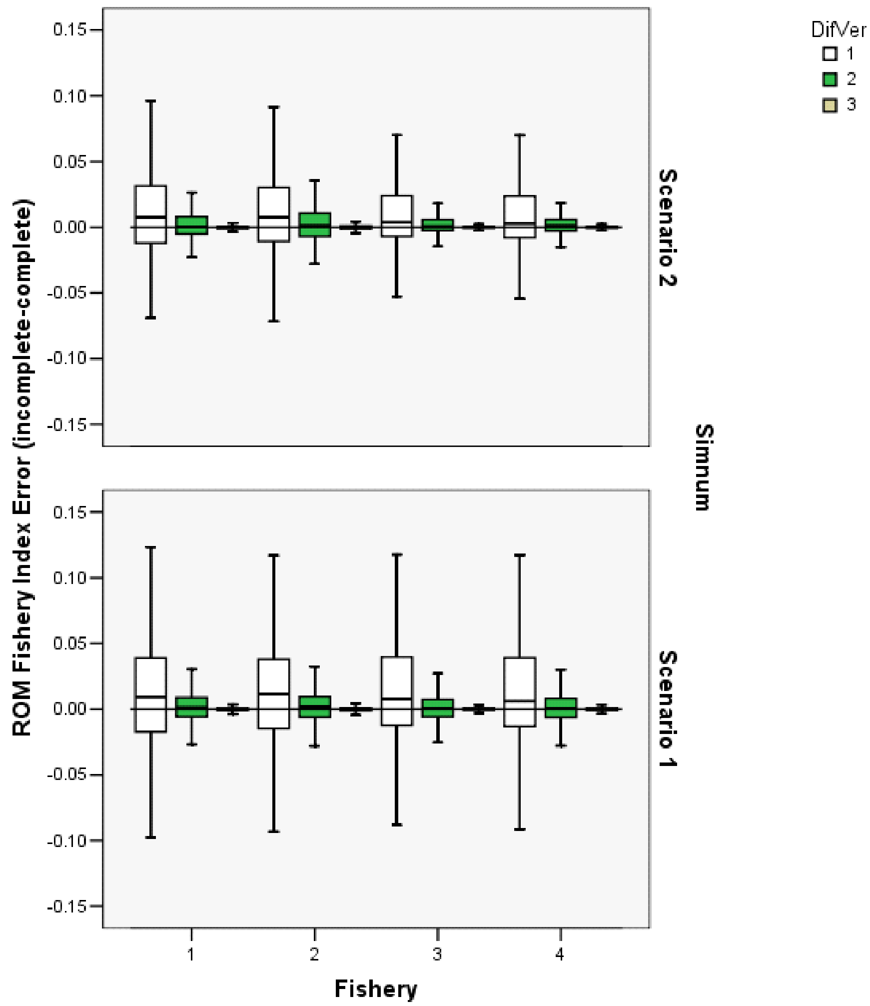


Figure 4-21. Box plots of the errors in the first, second and third incomplete version (DifVer) of the ROM HRI for fisheries 1 to 4 across all iterations, years, and samples for scenarios 1 and 2, with a reference line at 0.

Chapter 5. Evaluation of Harvest rate indices

5.1 True Index

The selection of a means to measure the True Annual Harvest Rate (TAHR) for a given fishery is essential to provide a consistent basis for evaluating the performance of alternatives metrics under consideration. The estimation of a TAHR from the Model data is not a trivial task. In the simulation model, the population structure in each fishery-time strata changes as fish are harvested, migrate, age, and mature, and as recruitment occurs through growth of existing cohorts and production of new age 2 cohorts.

Computing the true harvest rate (THR) for a fishery in a given period from the data generated by the simulation model is straightforward.

$$THR_{f,t} = \frac{C_{f,t}}{\sum_{s}\sum_{a} COH_{y,s,a,t} * PV_{s,a,t} * D_{f,s,a,t}} \qquad (5\text{-}1)$$

However, because the population structure in each fishery-time strata is changing within a given catch year, computing a TAHR is not straightforward.

The gauntlet statistic is an appropriate metric to reflect the TAHR. In a time-gauntlet, the fish are subjected to sequential fisheries, so that the cumulative survival rate is substracted from 1 to obtain the total annual fishery harvest rate for all time periods combined.

$$TAHR_{f,y} = 1 - \prod_{t} (1 - THR_{f,y,t}) \qquad (5\text{-}2)$$

In the analysis output files (TruAnn.CSV), we provide two types of annual harvest rate statistics from the simulated data for each run: (1) *Annual*; and (2) *Gauntlet*. The *Annual* statistic for a given fishery simply represents the total catch for all three time periods divided by the total vulnerable population (all stocks and ages combined) in time period 1. This statistic would only be appropriate when redistribution, growth, maturation, and recruitment are insignificant; this is clearly not the case for the current structure of the simulation model

5.1.1 Using the Gauntlet Statistic for evaluation of alternative HRIs.

For our evaluation, we are considering estimates of fishery harvest rates for six years (1982-1983, 1985-1986 and 1991-1992). Because some of the alternative fishery HRIs metrics we are evaluating are expressed as indices, true harvest rate indices (THRI) can be readily generated by dividing the TAHR for a given year by the 1982-1983 average TAHRs as the base.

$$THRI_{f,y} = \frac{TAHR_{f,y}}{0.5 * \sum_{y=1982}^{1983} TAHR_{f,y}} \tag{5-3}$$

5.2 HRI Evaluation Criteria

Numerous statistical measures are used to describe the goodness of fit for the HRIs. We cover a few of the standard ones used in linear model theory and incorporate a few more that are used in the non-linear and linear model theory.

5.2.1 Measure of goodness of fit on models (same number of parameters)

For most of the HRIs, we are looking at the same number of units for measuring the performance. For these estimates we computed two measure of compliance, one capturing the relative error, and the other capturing a measure of precision and error. The two criteria are summarized below:

5.2.1.1 Relative Error

Relative error was computed as a function of the estimated and observed HRI for the sampled (estimated) and simulated estimates (from the model). For this purpose, the statistic is estimated by,

$$RE_f = \frac{\hat{H}RI - HRI}{HRI} \times 100 \tag{5-4}$$

This statistic (RE) gives us a relative idea of the bias in the estimated measure of an index (HRI) for a fishery (f). An unbiased estimate would have on average a RE of zero.

5.2.1.2 Mean Square Error

We looked at another measure of error for a fishery; mean square error (MSE) which is equivalent to variance of some of the parameters used in the model if the parameter is Uniformly Minimum Variance Unbiased estimator (Casella and Berger 1990) implying it is unbiased (equation 4, Neter et. al. 1996). In other words, this might allow us to compare different parameters in equivalent models (same number of parameters) and choose ones which have the minimal mean square error or variance.

The MSE of the parameter is,

$$MSE(\hat{H}RI) = E\left[\left(HRI - \hat{H}RI \right)^2 \right] \tag{5-5}$$

And

$$MSE(\hat{H}RI) = \mathrm{var}(\hat{H}RI) + bias(\hat{H}RI)^2 . \tag{5-6}$$

So, in our analysis there are η (number of simulations times the number of samples) Independent Identically Distributed (iid) HRI estimates for each fishery and year, the Central Limit Theorem states that if the HRIs have mean μ and variance σ^2 and η is large then the average of the HRIs ($HRI_{f,y,i} \ldots\ldots HRI_{f,y,\eta}$) should be approximately normally distributed with mean μ and variance σ^2/η,

$$\overline{HRI}_{f,y} = \frac{1}{\eta}\sum_{i=1}^{\eta} HRI_{f,y,i} \sim N\left(\mu, \frac{\sigma^2}{\eta}\right). \quad (5\text{-}7)$$

Furthermore, the average of the HRIs should be unbiased so

$$MSE(\overline{HRI}_{f,y}) = Var(\overline{HRI}_{f,y}) = \frac{\sigma^2}{\eta} \quad (5\text{-}8)$$

for fishery *f* and year *y*. The root MSE (RMSE) is then

$$RMSE(\overline{HRI}_{f,y}) = \sqrt{MSE(\overline{HRI}_{f,y})}. \quad (5\text{-}9)$$

The RMSE can be used as a comparison tool to judge how well various estimators perform. Estimators with lower RMSE values are judged to be superior to those with higher RMSE values. This method would be applicable for comparing the SA and ROM HRI metrics.

5.2.2 Likelihood of a HRI

Once estimators become more complex and non-linear in nature, we need to either transform the data to a linear form and compare derived estimates or go to alternative measures such as the Likelihood of the estimator given the data. In the case of the HRI estimators evaluated here, we have multiple HRIs based on our samples. We multiply these together (assuming independence), or

$$L(p \mid HRI_1, HRI_2, \ldots\ldots) = L(p \mid HRI_1) L(p \mid HRI_2) \ldots\ldots \quad (5\text{-}10)$$

In our case, this is based on the index in a fishery compared with the true value, for each replicate and run. This will be computed for a specific fishery. So, for fishery 1, if there are 25 iterations and 10 samples there are 250 such values that are multiplied together.

The actual likelihood equation is:

$$L(p \mid HRI_i) = \frac{1}{\sqrt{2\pi\sigma_f^2}} \exp\left[-\frac{\left(\ln(HRI_i) - \ln(\overline{HRI}_i)\right)^2}{2\sigma_f^2} \right] \quad (5\text{-}11)$$

Where p is the set of parameters used to project the HRI in fishery (f), and $\sigma_f^{\,2}$ is the variance term which can be approximated with a close formed solution.

Finally, the maximum likelihood is obtained by multiplying all values together as shown below:

$$\prod_{i=1}^{\eta} L(p \mid HRI_i) = \prod_{i=1}^{\eta} \frac{1}{\sqrt{2\pi\sigma_f^{\,2}}} \exp\left[-\frac{\left(\ln(HRI_i) - \ln(\overline{HRI}_i)\right)^2}{2\sigma_f^{\,2}} \right] \qquad (5\text{-}12)$$

where η is the number of data points in the fishery strata.

If we have the same number of parameters, these will essentially be equivalent to the MSE results. However, if we are comparing across models with different number of parameters (e.g. the SPFI from the simulations has 3 strata, and the same number of stocks are used in each strata (so the number of parameters used in the SPFI calculations are multiplied by 3k, where k is the number of parameters used). In such cases we compute a statistic known as the AIC.

5.2.3 Akaike Information Criteria (AIC)

In most methods covered so far, we have mentioned estimators with equivalent number of parameters. However, we might have estimators with a certain number of parameters with a better fit as compared to the estimators with fewer parameters. If we look at the simple likelihood (or Log likelihood) of the fit, the estimator with more parameters may appear to fit the data better, but the estimator is penalized for having too many parameters. For this type of comparison the AIC penalizes the log-likelihood by adding twice the number of parameters to the overall likelihood value (Akaike 1992).

$$AIC = -2Log(L) + 2k \qquad (5\text{-}13)$$

where k is the number of parameters in the estimator and L is the likelihood of the fit of the estimator.

5.3 Fishery Specific Analysis

Based on the analysis done on individual stock indices, we noticed that the indices varied by year of estimate (incomplete to complete brood). However, after the first year (i.e., the catch year) the indices tended to stabilize. Since the HRI follows the stock specific indices over time, we decided to only present the results of the final HRI (i.e. complete brood analysis). We looked at how different indices performed over the years. The methods illustrated here show how these metrics performed for the complete brood analysis, as in most cases that would be the most accurate method to evaluate based on the simulation.

In order to compare some of the merits of the criteria (statistics) used for the analyses, we compiled a table below showing different properties of these criteria (Table 5-1). Relative error, although not presented in Table 5-1, essentially gives us an idea as to the bias of a given estimator.

Table 5-1. Properties of the model performance criteria with specific attributes.

PROPERTIES	RMSE	Likelihood	AIC
What is measured?	Direct measure of Bias and Precision	Direct Measure of bias and precision + weight of fit to the data.	Direct Measure of Bias and precision + Weight of Fit to the data + Penalty for model parameters
Responsiveness to Differences in Model Structure	Treats all models the same	Treats all models the same	Penalizes models with more parameters.
Outcome/Tendency	Favors complex models	Favors complex models	Favors simple models (Parsimony)

5.3.1 Summary Statistics for the ROM for Scenario 1

Relative error was computed for the 4 fisheries in each of the years being evaluated (Figure 5-1). In the base years the error distribution is fairly small, but as the fishery changes in 1985 and 1986 and 1991 to 1992, the error becomes larger, though the estimate is still unbiased, but may have some skew to it (especially for Fishery 1 and 2). Table 5-2 reports the actual statistics that are shown in Figure 5-1, as well as the maximum relative error in each fishery and year for a particular statistic.

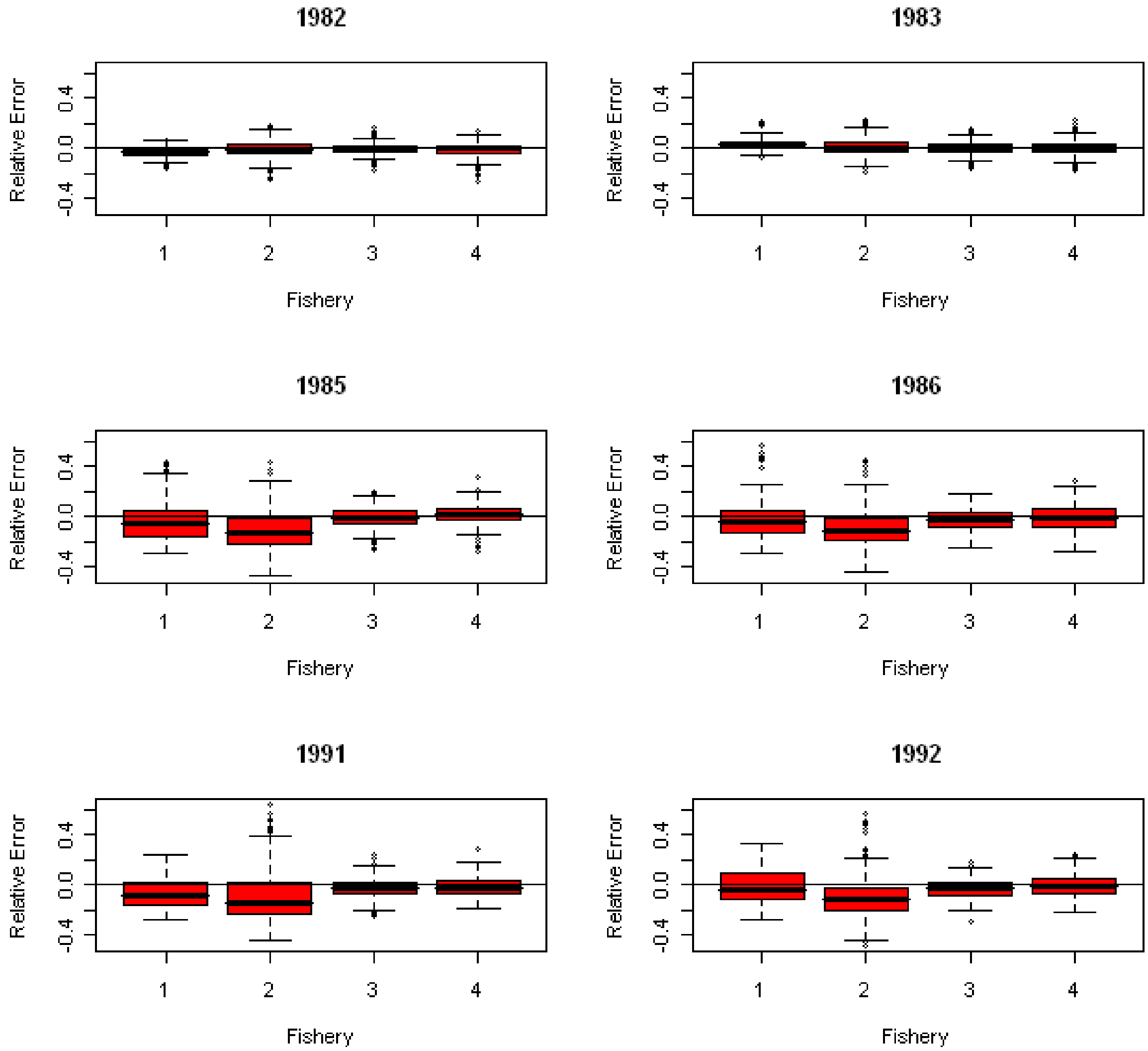


Figure 5-1 Relative Error of ROM estimate against the True value for Scenario 1. Each panel depicts a separate year. The x-axis displays the fishery, and the y-axis displays the relative error. The box displays the 25th and 75th quartiles of the relative error distribution, and the whiskers display the 5th and 95th percentiles (i.e. 1.645*the standard error).

Table 5-2. Summary statistics of the relative error distribution for each fishery using ROM for Scenario 1.

FISHERY	Min	1st Qt	Median	Mean	3rd Qt	Max
Year = 1982						
Fishery 1	-15%	-5%	-3%	-3%	0%	7%
Fishery 2	-25%	-5%	-1%	-1%	3%	18%
Fishery 3	-18%	-3%	0%	-1%	2%	16%
Fishery 4	-27%	-4%	-1%	-2%	2%	14%
Year = 1983						
Fishery 1	-7%	0%	3%	3%	5%	21%
Fishery 2	-19%	-3%	1%	1%	5%	22%
Fishery 3	-16%	-3%	0%	0%	3%	14%
Fishery 4	-18%	-3%	1%	0%	4%	22%
Year = 1985						
Fishery 1	-29%	-16%	-6%	-4%	4%	43%
Fishery 2	-47%	-22%	-12%	-11%	-2%	42%
Fishery 3	-26%	-5%	-1%	-1%	4%	20%
Fishery 4	-29%	-3%	1%	1%	6%	31%
Year = 1986						
Fishery 1	-30%	-13%	-4%	-3%	5%	56%
Fishery 2	-44%	-20%	-11%	-10%	-1%	44%
Fishery 3	-25%	-9%	-2%	-3%	4%	17%
Fishery 4	-28%	-8%	-1%	-1%	5%	28%
Year = 1991						
Fishery 1	-28%	-16%	-9%	-6%	1%	25%
Fishery 2	-44%	-24%	-15%	-9%	1%	63%
Fishery 3	-25%	-7%	-3%	-3%	2%	24%
Fishery 4	-20%	-7%	-2%	-2%	3%	28%
Year = 1992						
Fishery 1	-29%	-12%	-5%	-3%	9%	32%
Fishery 2	-48%	-20%	-12%	-10%	-3%	57%
Fishery 3	-30%	-8%	-3%	-4%	1%	18%
Fishery 4	-23%	-7%	-1%	0%	5%	23%

5.3.2 Summary Statistics for the SA for Scenario 1

The SA relative error is smaller than the ROM on average, though in Fishery 1 and 2 in the transition years (1985 and 1986) and the new fishery years (1991 and 1992) the SA appears to have points that are out beyond the 5^{th} or 95^{th} percentiles (more points on the tails than with the ROM). In general though, the bias in transition years now appears to be positive (Figure 5-2) versus with the ROM it appeared to be negative (Figure 5-1). Similar to Table 5-2, Table 5-3 displays the actual values of the distributions (quartiles, median, minimum and maximums) by fishery and year for the SA relative error distributions.

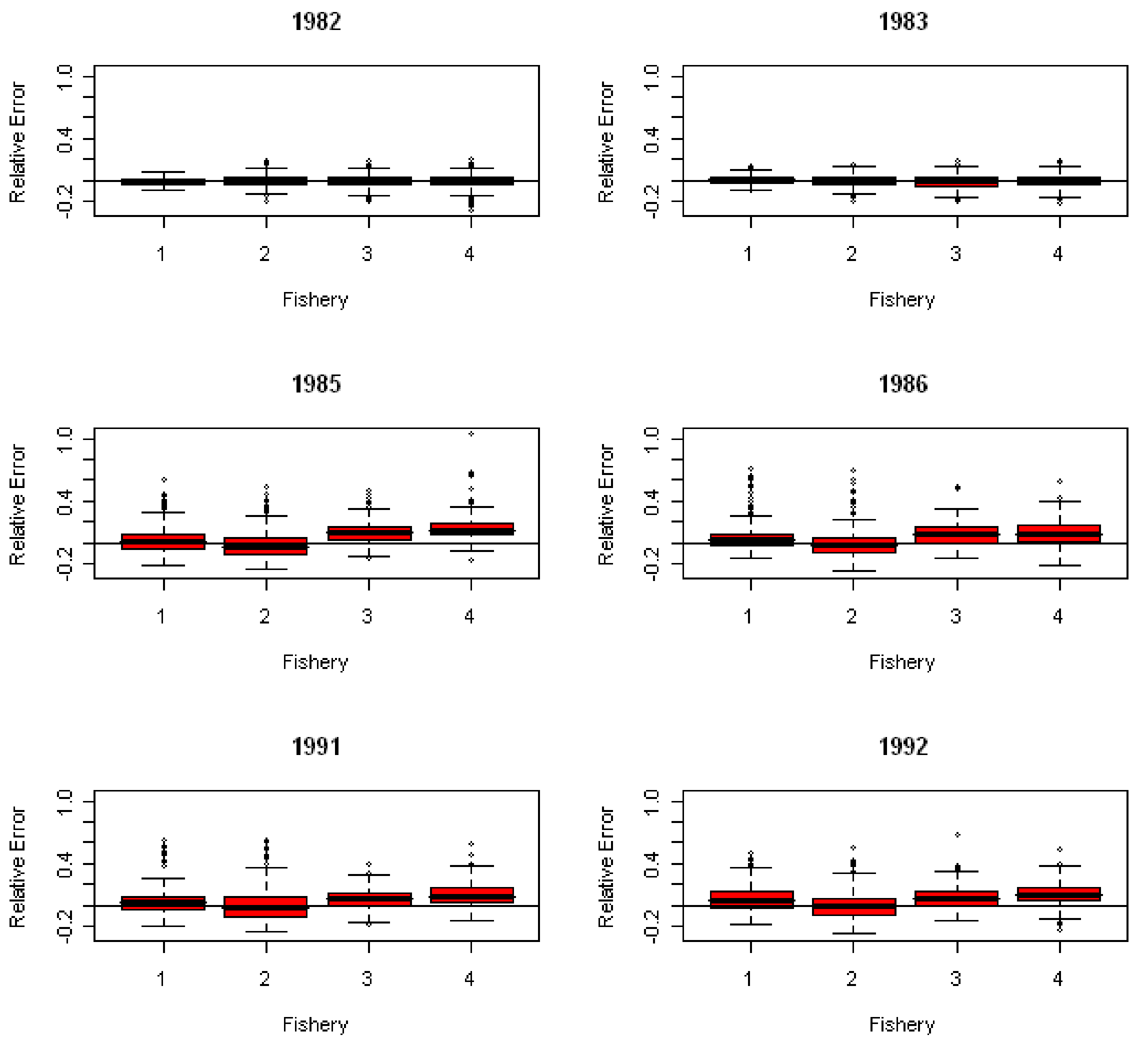


Figure 5-2. Relative Error of SA estimate against the True value using all Brood years for Scenario 1. The x-axis displays the fishery, and the y-axis displays the relative error. The box displays the 25th and 75th quartiles of the relative error distribution, and the whiskers display the 5th and 95th percentiles (i.e. 1.645*the standard error).

Table 5-3. Summary statistics for the relative error distribution for each fishery and year using SA.

FISHERY	Min	1st Qt	Median	Mean	3rd Qt	Max
Year = 1982						
Fishery 1	-8.2%	-2.3%	0.0%	0.5%	3.4%	12.2%
Fishery 2	-18.6%	-2.5%	0.9%	0.6%	4.2%	21.1%
Fishery 3	-19.0%	-3.7%	0.0%	0.0%	3.5%	37.7%
Fishery 4	-29.7%	-5.6%	-0.5%	-1.9%	2.6%	28.9%
Year = 1983						
Fishery 1	-11.4%	-2.9%	0.0%	-0.3%	2.1%	9.0%
Fishery 2	-19.2%	-4.1%	-0.8%	-0.5%	2.4%	20.2%
Fishery 3	-18.2%	-2.7%	0.0%	-0.8%	1.7%	17.0%
Fishery 4	-19.2%	-2.1%	0.4%	-0.4%	2.3%	10.5%
Year = 1985						
Fishery 1	-19.5%	-0.7%	5.7%	8.5%	14.9%	64.1%
Fishery 2	-31.3%	-7.6%	1.3%	4.0%	12.2%	59.3%
Fishery 3	-33.7%	-1.6%	6.9%	10.6%	16.3%	150.6%
Fishery 4	-26.0%	0.2%	8.0%	10.3%	16.7%	143.1%
Year = 1986						
Fishery 1	-15.9%	-3.8%	2.7%	6.6%	9.7%	96.5%
Fishery 2	-26.7%	-6.3%	0.9%	3.0%	8.6%	81.2%
Fishery 3	-35.5%	-0.1%	6.4%	9.6%	17.3%	107.0%
Fishery 4	-31.0%	1.2%	8.7%	11.0%	21.2%	54.9%
Year = 1991						
Fishery 1	-19.1%	-4.3%	1.7%	3.5%	10.9%	38.7%
Fishery 2	-26.1%	-6.6%	0.3%	1.3%	8.0%	38.9%
Fishery 3	-22.9%	0.3%	7.5%	9.2%	14.7%	88.7%
Fishery 4	-18.5%	1.5%	10.4%	9.5%	17.0%	86.6%
Year = 1992						
Fishery 1	-24.0%	-2.8%	3.0%	3.8%	8.7%	34.3%
Fishery 2	-32.4%	-7.2%	-1.9%	0.5%	6.9%	69.6%
Fishery 3	-32.4%	-2.5%	5.8%	7.6%	15.3%	71.0%
Fishery 4	-29.6%	2.8%	11.6%	13.7%	21.8%	120.4%

5.3.3 Summary Statistics for the SPFI for Scenario 1

The SPFI appears to be the most precise of the 3 measures used to evaluate the HRIs. The relative error is in general negative (Figure 5-3). However, in all cases, the 95^{th} percentile (indicated by the whiskers) covered zero, indicating no systematic bias. One should note, however that for Fishery 1 and 2 after 1985 the SPFI tends to underestimate the true value and the quartile ranges show this as well (Figure 5-3). Table 5-4 displays the actual values of the distributions (quartiles, median, minimum and maximums) by Fishery and Year for the SPFI relative error distributions.

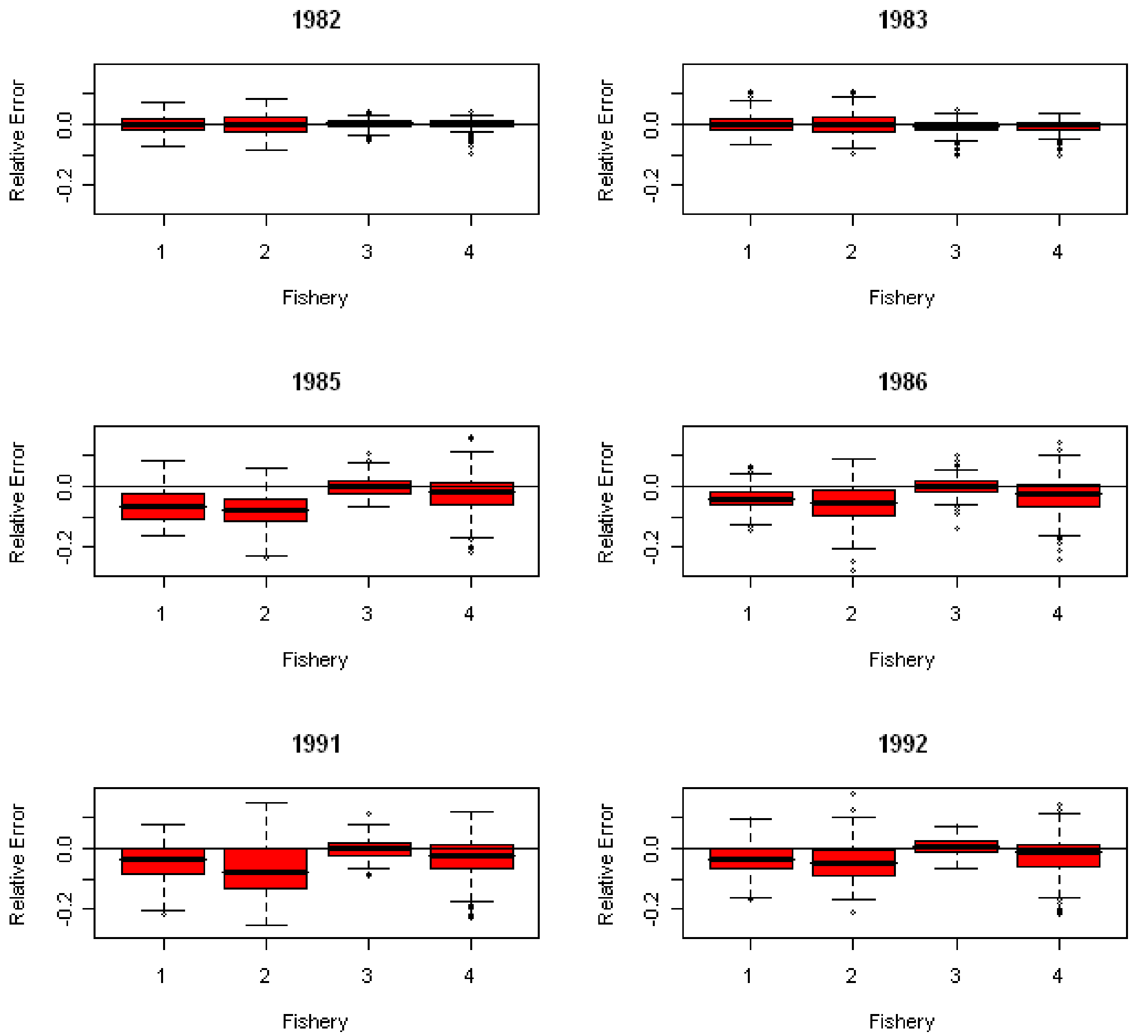


Figure 5-3. SPFI relative error for Scenario 1. The x-axis displays the fishery, and the y-axis displays the relative error. The box displays the 25th and 75th quartiles of the relative error distribution, and the whiskers display the 5th and 95th percentiles (i.e. 1.645*the standard error).

Table 5-4. Summary statistics of the relative error distribution for each fishery using SPFI for Scenario 1.

FISHERY	Min	1st Qt	Median	Mean	3rd Qt	Max
Year = 1982						
Fishery 1	-7.6%	-2.0%	0.0%	-0.2%	1.8%	6.9%
Fishery 2	-8.7%	-2.4%	0.1%	0.0%	2.4%	8.4%
Fishery 3	-5.4%	-0.8%	0.3%	-0.1%	1.0%	4.3%
Fishery 4	-9.6%	-0.6%	0.2%	-0.1%	0.9%	4.0%
Year = 1983						
Fishery 1	-6.7%	-1.8%	0.0%	0.3%	2.0%	10.6%
Fishery 2	-9.5%	-2.4%	-0.1%	0.1%	2.2%	10.5%
Fishery 3	-10.4%	-2.1%	-0.4%	-0.9%	0.6%	4.8%
Fishery 4	-10.0%	-1.7%	-0.3%	-0.8%	0.5%	3.4%
Year = 1985						
Fishery 1	-16.4%	-10.8%	-6.9%	-6.4%	-2.8%	8.2%
Fishery 2	-23.7%	-11.8%	-8.1%	-8.3%	-4.1%	5.9%
Fishery 3	-6.4%	-2.2%	0.1%	0.1%	1.9%	10.9%
Fishery 4	-21.9%	-5.8%	-1.8%	-2.5%	1.4%	16.1%
Year = 1986						
Fishery 1	-14.4%	-6.0%	-4.1%	-3.9%	-1.8%	6.9%
Fishery 2	-27.7%	-9.6%	-5.4%	-5.6%	-1.3%	9.0%
Fishery 3	-13.8%	-1.5%	0.0%	0.0%	1.5%	10.2%
Fishery 4	-24.4%	-6.3%	-2.4%	-3.2%	0.3%	14.7%
Year = 1991						
Fishery 1	-22.0%	-8.4%	-3.9%	-4.8%	-0.1%	7.5%
Fishery 2	-25.3%	-13.4%	-7.6%	-6.6%	0.1%	14.9%
Fishery 3	-8.8%	-2.4%	-0.2%	-0.2%	1.6%	11.3%
Fishery 4	-22.7%	-6.6%	-2.5%	-3.2%	1.2%	12.2%
Year = 1992						
Fishery 1	-17.0%	-6.6%	-3.4%	-3.4%	-0.2%	9.7%
Fishery 2	-21.3%	-8.8%	-4.7%	-4.3%	-0.6%	17.8%
Fishery 3	-6.5%	-1.3%	0.5%	0.4%	2.1%	7.5%
Fishery 4	-21.8%	-5.6%	-1.5%	-2.6%	1.4%	14.6%

5.3.4 Summary for Scenario 1

Table 5-5 summarizes results from Table 5-2, Table 5-3 and Table 5-4. This table has a side by side comparison of the three median values to assess which estimator performs the best. It appears from Table 5-5 that the least unbiased statistic is the SA. The SPFI is comparable, however it tends to underestimate the true value (as indicated by the negative sign), whereas the SA tends to overestimate the true value (Table 5-5).

Table 5-6 shows the three statistical criteria that were developed to evaluate how these estimators measure against the true value (i.e. the gauntlet statistic). The first set is the

SPFI, the next is the ROM and the third set is the SA. Highlighted cells indicate which estimator performed the best in the particular year and fishery strata. The three statistics evaluated are: i) RMSE (indicated by yellow highlights), ii) Likelihood (indicated by cyan highlight), and iii) AIC indicated by (purple highlight). A low RMSE indicates a better fit, the lowest value on the negative likelihood indicates a better fit, and the lowest value on the AIC indicates a better fit. In all three cases, the SPFI appears to perform the best (other than Fishery 1 in the base years of 1982 and 1983, Table 5-6).

Table 5-5. Relative Error of the HRIs based on median values for Scenario 1.

Year = 1982			
FISHERY	**ROM**	**SA**	**SPFI**
Fishery 1	-3%	0.0%	0.0%
Fishery 2	-1%	0.9%	0.1%
Fishery 3	0%	0.0%	0.3%
Fishery 4	-1%	-0.5%	0.2%
Year = 1983			
Fishery 1	3%	0.0%	0.0%
Fishery 2	1%	-0.8%	-0.1%
Fishery 3	0%	0.0%	-0.4%
Fishery 4	1%	0.4%	-0.3%
Year = 1985			
Fishery 1	-6%	5.7%	-6.9%
Fishery 2	-12%	1.3%	-8.1%
Fishery 3	-1%	6.9%	0.1%
Fishery 4	1%	8.0%	-1.8%
Year = 1986			
Fishery 1	-4%	2.7%	-4.1%
Fishery 2	-11%	0.9%	-5.4%
Fishery 3	-2%	6.4%	0.0%
Fishery 4	-1%	8.7%	-2.4%
Year = 1991			
Fishery 1	-9%	1.7%	-3.9%
Fishery 2	-15%	0.3%	-7.6%
Fishery 3	-3%	7.5%	-0.2%
Fishery 4	-2%	10.4%	-2.5%
Year = 1992			
Fishery 1	-5%	3.0%	-3.4%
Fishery 2	-12%	-1.9%	-4.7%
Fishery 3	-3%	5.8%	0.5%
Fishery 4	-1%	11.6%	-1.5%
Average	-3.6%	3.3%	-2.2%

Table 5-6. Overall side by side comparisons for three fisheries between ROM, SA and SPFI for Scenario 1.

SPFI				ROM				SA			
FISHERY	**RMSE**	**Likelihood**	**AIC**	**FISHERY**	**RMSE**	**Likelihood**	**AIC**	**FISHERY**	**RMSE**	**Likelihood**	**AIC**
Year = 1982				Year = 1982				Year = 1982			
Fishery 1	0.00011	-538.49	-849.95	Fishery 1	0.00021	-379	-682	Fishery 1	0.00015	-469	-862
Fishery 2	0.00014	-485.47	-782.31	Fishery 2	0.00027	-317	-570	Fishery 2	0.00022	-371	-679
Fishery 3	0.00006	-694.36	-1198.71	Fishery 3	0.00016	-443	-822	Fishery 3	0.00020	-388	-713
Fishery 4	0.00006	-714.18	-1238.43	Fishery 4	0.00018	-420	-777	Fishery 4	0.00022	-376	-688
Year = 1983				Year = 1983				Year = 1983			
Fishery 1	0.00011	-538.49	-849.95	Fishery 1	0.00021	-379	-682	Fishery 1	0.00015	-469	-862
Fishery 2	0.00014	-485.47	-782.31	Fishery 2	0.00027	-317	-570	Fishery 2	0.00022	-371	-679
Fishery 3	0.00006	-694.36	-1198.71	Fishery 3	0.00016	-443	-822	Fishery 3	0.00020	-388	-713
Fishery 4	0.00006	-714.18	-1238.43	Fishery 4	0.00018	-420	-777	Fishery 4	0.00022	-376	-688
Year = 1985				Year = 1985				Year = 1985			
Fishery 1	0.00037	-242.05	-257.05	Fishery 1	0.00068	-87	-97	Fishery 1	0.00060	-118	-160
Fishery 2	0.00045	-189.84	-191.07	Fishery 2	0.00080	-47	-31	Fishery 2	0.00059	-122	-181
Fishery 3	0.00022	-373.20	-556.38	Fishery 3	0.00050	-167	-270	Fishery 3	0.00119	51	165
Fishery 4	0.00037	-240.98	-292.03	Fishery 4	0.00064	-103	-142	Fishery 4	0.00178	152	368
Year = 1986				Year = 1986				Year = 1986			
Fishery 1	0.00023	-364.27	-501.49	Fishery 1	0.00060	-121	-166	Fishery 1	0.00060	-119	-163
Fishery 2	0.00035	-255.33	-322.04	Fishery 2	0.00074	-66	-69	Fishery 2	0.00054	-148	-232
Fishery 3	0.00016	-457.22	-724.43	Fishery 3	0.00042	-207	-351	Fishery 3	0.00077	-56	-48
Fishery 4	0.00025	-343.22	-496.51	Fishery 4	0.00041	-213	-363	Fishery 4	0.00081	-44	-25
Year = 1991				Year = 1991				Year = 1991			
Fishery 1	0.00036	-245.57	-264.09	Fishery 1	0.00061	-87	-155	Fishery 1	0.00060	-121	-167
Fishery 2	0.00049	-168.02	-147.42	Fishery 2	0.00096	-47	60	Fishery 2	0.00070	-82	-100
Fishery 3	0.00017	-434.40	-678.79	Fishery 3	0.00041	-167	-361	Fishery 3	0.00091	-16	32
Fishery 4	0.00032	-273.41	-356.88	Fishery 4	0.00053	-103	-237	Fishery 4	0.00137	86	236
Year = 1992				Year = 1992				Year = 1992			
Fishery 1	0.00028	-312.51	-397.97	Fishery 1	0.00059	-122	-168	Fishery 1	0.00063	-107	-138
Fishery 2	0.00033	-267.18	-345.75	Fishery 2	0.00093	-11	42	Fishery 2	0.00060	-119	-175
Fishery 3	0.00020	-399.25	-608.50	Fishery 3	0.00055	-140	-217	Fishery 3	0.00104	19	102
Fishery 4	0.00030	-292.21	-394.48	Fishery 4	0.00051	-160	-256	Fishery 4	0.00110	32	127

5.3.5 Summary Statistics for the ROM for Scenario 2

Relative error was computed from these 4 fisheries in each of the years being evaluated (Figure 5-4). These results are summarized by fishery and year with their quartiles in Table 5-7. Similar trends as those observed with the ROM in Scenario 1 (Figure 5-1). In the base years the error distribution is fairly small, but as the fishery changes in 1985 and 1986 and 1991 to 1992, the error appears to become larger, though is still unbiased, but may have some skew to it (especially for Fishery 1 and 2). Table 5-7 reports the actual statistics that are shown in Figure 5-4, as well as the maximum relative error in each fishery and year for a particular statistic.

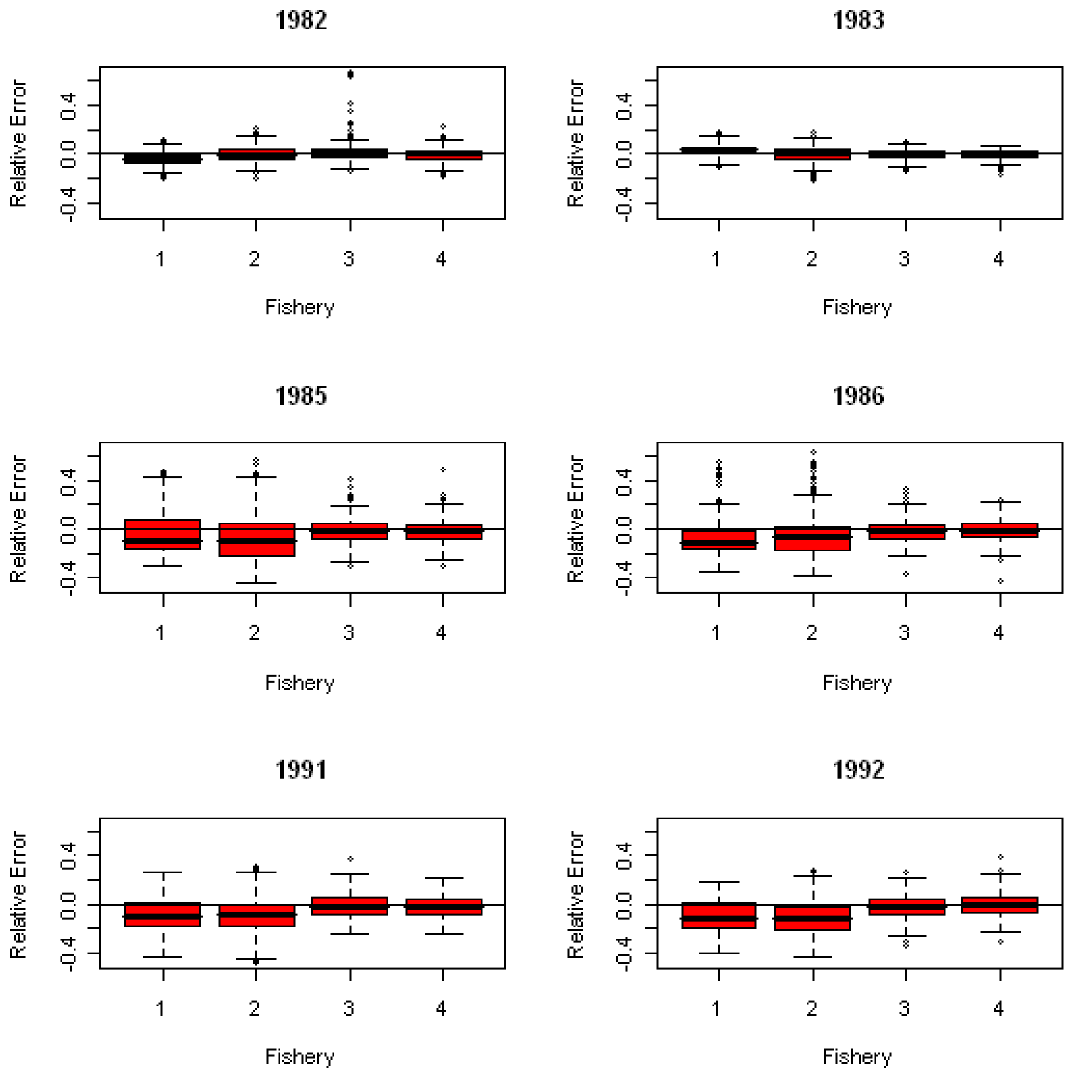


Figure 5-4. Relative Error of ROM estimate against the True value for Scenario 2. The x-axis displays the fishery, and the y-axis displays the relative error. The box displays the 25th and 75th quartiles of the relative error distribution, and the whiskers display the 5th and 95th percentiles (i.e. 1.645*the standard error).

Table 5-7. Summary statistics for the relative error distribution for each fishery using ROM for Scenario 2.

FISHERY	Min	1st Qt	Median	Mean	3rd Qt	Max
Year = 1982						
Fishery 1	-20%	-6%	-4%	-4%	0%	11%
Fishery 2	-20%	-4%	0%	0%	4%	22%
Fishery 3	-14%	-3%	0%	2%	3%	66%
Fishery 4	-19%	-4%	0%	-1%	3%	23%
Year = 1983						
Fishery 1	-11%	0%	3%	4%	6%	19%
Fishery 2	-21%	-3%	0%	0%	4%	18%
Fishery 3	-14%	-3%	0%	-1%	1%	11%
Fishery 4	-16%	-2%	0%	-1%	2%	7%
Year = 1985						
Fishery 1	-30%	-16%	-9%	-4%	7%	47%
Fishery 2	-43%	-21%	-9%	-7%	5%	57%
Fishery 3	-30%	-8%	-2%	-1%	4%	41%
Fishery 4	-30%	-8%	-2%	-2%	4%	49%
Year = 1986						
Fishery 1	-35%	-16%	-11%	-6%	-1%	55%
Fishery 2	-38%	-17%	-7%	-6%	1%	63%
Fishery 3	-35%	-8%	-2%	-1%	4%	34%
Fishery 4	-42%	-7%	-2%	-1%	5%	23%
Year = 1991						
Fishery 1	-42%	-18%	-10%	-9%	1%	26%
Fishery 2	-48%	-18%	-9%	-9%	0%	31%
Fishery 3	-25%	-8%	-2%	-1%	5%	38%
Fishery 4	-24%	-9%	-2%	-2%	4%	22%
Year = 1992						
Fishery 1	-40%	-19%	-11%	-10%	1%	19%
Fishery 2	-43%	-21%	-11%	-11%	-2%	29%
Fishery 3	-33%	-9%	-2%	-3%	4%	27%
Fishery 4	-30%	-7%	-1%	0%	6%	39%

5.3.6 Simple Average Summary Statistics for Scenario 2

SA relative error distributions are displayed in Figure 5-5. The bias appears to be minimal as before, though for Fishery 4 in the later years (1992) this relative error has a large number of points that tend to overestimate the true value (numerous points at the tail). Table 5-8 captures the actual values displayed in Figure 5-5.

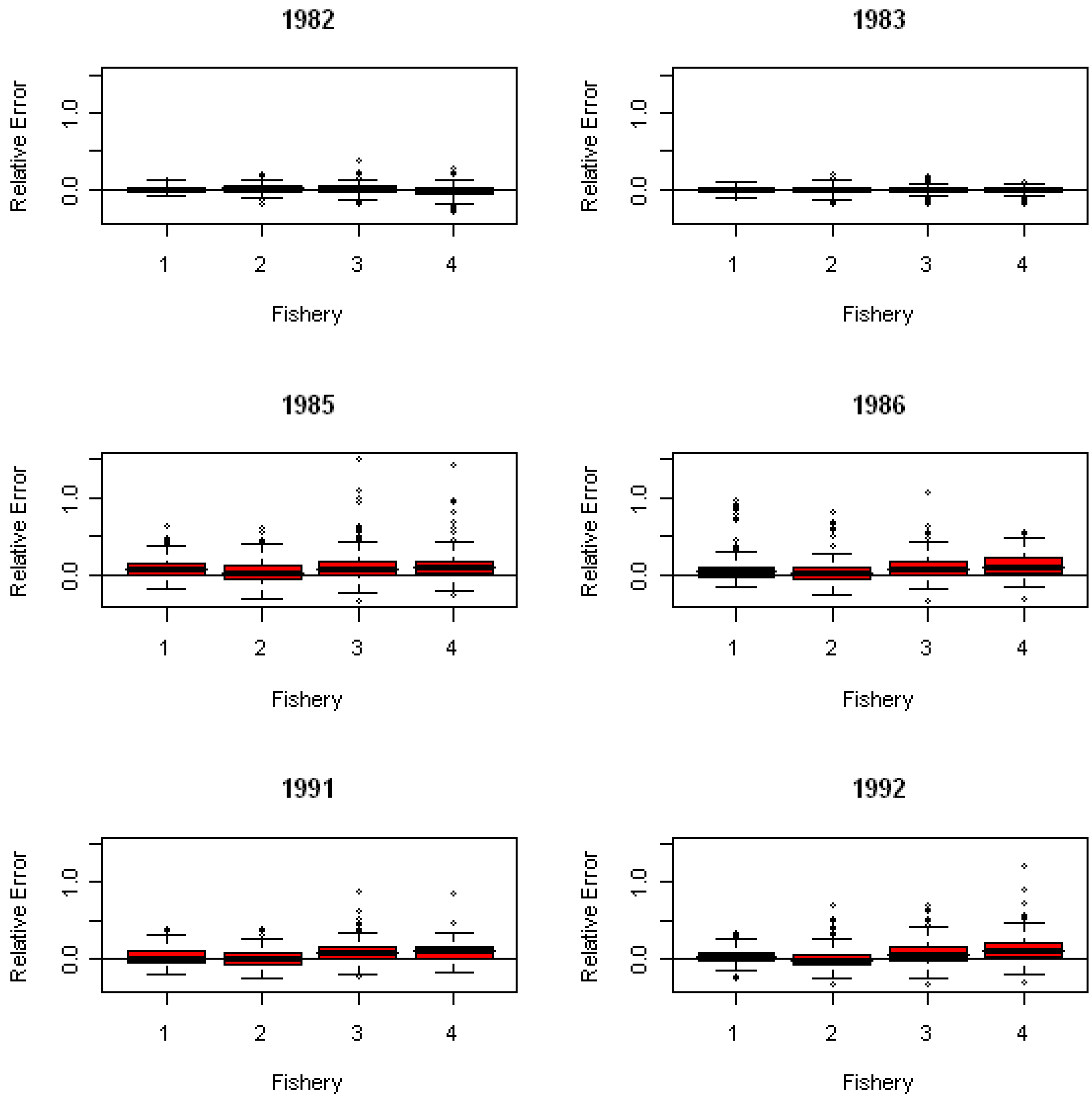


Figure 5-5. Relative Error of SA estimate against the True value for Scenario 2. The x-axis displays the fishery, and the y-axis displays the relative error. The box displays the 25th and 75th quartiles of the relative error distribution, and the whiskers display the 5th and 95th percentiles (i.e. 1.645*the standard error).

Table 5-8. Summary statistics for the relative error distribution for each fishery and year using SA for Scenario 2.

FISHERY	Min	1st Qt	Median	Mean	3rd Qt	Max
Year = 1982						
Fishery 1	-8%	-2%	0%	0%	3%	12%
Fishery 2	-19%	-3%	1%	1%	4%	21%
Fishery 3	-19%	-4%	0%	0%	4%	38%
Fishery 4	-30%	-6%	0%	-2%	3%	29%
Year = 1983						
Fishery 1	-11%	-3%	0%	0%	2%	9%
Fishery 2	-19%	-4%	-1%	-1%	2%	20%
Fishery 3	-18%	-3%	0%	-1%	2%	17%
Fishery 4	-19%	-2%	0%	0%	2%	10%
Year = 1985						
Fishery 1	-19%	-1%	6%	9%	15%	64%
Fishery 2	-31%	-8%	1%	4%	12%	59%
Fishery 3	-34%	-2%	7%	11%	16%	151%
Fishery 4	-26%	0%	8%	10%	17%	143%
Year = 1986						
Fishery 1	-16%	-4%	3%	7%	10%	96%
Fishery 2	-27%	-6%	1%	3%	9%	81%
Fishery 3	-35%	0%	6%	10%	17%	107%
Fishery 4	-31%	1%	9%	11%	21%	55%
Year = 1991						
Fishery 1	-19%	-4%	2%	3%	11%	39%
Fishery 2	-26%	-7%	0%	1%	8%	39%
Fishery 3	-23%	0%	7%	9%	15%	89%
Fishery 4	-18%	2%	10%	9%	17%	87%
Year = 1992						
Fishery 1	-24%	-3%	3%	4%	9%	34%
Fishery 2	-32%	-7%	-2%	0%	7%	70%
Fishery 3	-32%	-2%	6%	8%	15%	71%
Fishery 4	-30%	3%	12%	14%	22%	120%

5.3.7 Stratified Proportional Fishery Index for Scenario 2

Relative error distributions for the SPFI (Figure 5-6) indicate similar trends as with Scenario 1. The SPFI median value appears to underestimate the true value for Fishery 1, 2 and 4 after the fishery patterns start changing (Table 5-9).

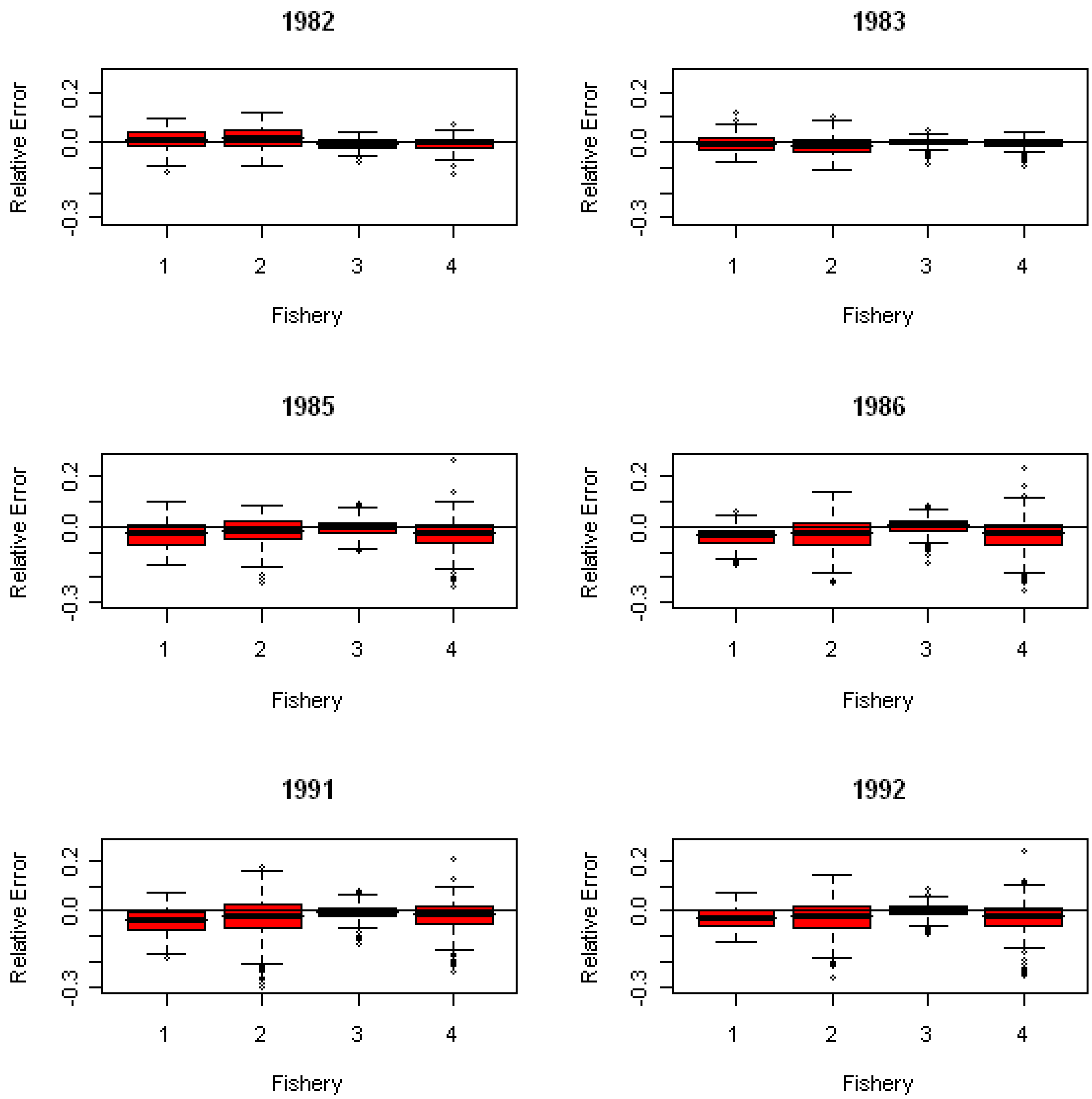


Figure 5-6. SPFI Relative error for Scenario 2. The x-axis displays the fishery, and the y-axis displays the relative error. The box displays the 25th and 75th quartiles of the relative error distribution, and the whiskers display the 5th and 95th percentiles (i.e. 1.645*the standard error).

Table 5-9. Summary statistics of the relative error distribution for each fishery using SPFI for Scenario 2.

FISHERY	Min	1st Qt	Median	Mean	3rd Qt	Max
Year = 1982						
Fishery 1	-12%	-1%	1%	1%	4%	9%
Fishery 2	-9%	-1%	2%	1%	4%	12%
Fishery 3	-7%	-2%	0%	-1%	1%	4%
Fishery 4	-12%	-2%	0%	-1%	1%	7%
Year = 1983						
Fishery 1	-8%	-3%	-1%	-1%	1%	11%
Fishery 2	-11%	-4%	-1%	-1%	1%	10%
Fishery 3	-9%	-1%	0%	0%	1%	4%
Fishery 4	-9%	-1%	0%	0%	1%	4%
Year = 1985						
Fishery 1	-15%	-8%	-2%	-3%	0%	10%
Fishery 2	-22%	-5%	-1%	-2%	2%	8%
Fishery 3	-9%	-2%	0%	0%	2%	9%
Fishery 4	-24%	-7%	-2%	-3%	0%	26%
Year = 1986						
Fishery 1	-15%	-6%	-3%	-4%	-2%	6%
Fishery 2	-22%	-7%	-2%	-3%	2%	14%
Fishery 3	-14%	-2%	0%	0%	2%	9%
Fishery 4	-25%	-7%	-3%	-3%	1%	24%
Year = 1991						
Fishery 1	-18%	-7%	-4%	-4%	0%	8%
Fishery 2	-30%	-7%	-2%	-3%	3%	17%
Fishery 3	-13%	-2%	0%	0%	1%	8%
Fishery 4	-24%	-5%	-2%	-3%	2%	21%
Year = 1992						
Fishery 1	-12%	-6%	-3%	-3%	0%	7%
Fishery 2	-26%	-7%	-2%	-3%	2%	14%
Fishery 3	-9%	-2%	0%	0%	2%	9%
Fishery 4	-25%	-6%	-2%	-3%	1%	23%

5.3.8 Summary for Scenario 2, Run 1

The median bias still remains consistent as in Scenario 1, i.e. the true value seems to be underestimated by the SPFI and ROM and overestimated by the SA (Table 5-10) though they are very close to zero and in all cases cross the 0 line in terms of confidence intervals (Figure 5-4 to Figure 5-6). Table 5-11 shows the three statistical criteria that were developed to evaluate how these indices measure against the true value (i.e. the gauntlet statistic). The first set is the SPFI, the next is the ROM and the third set is the SA. Highlighted cells indicate which statistic performed the best in the particular year and fishery strata. The three statistics evaluated are: i) RMSE (indicated by yellow highlights), ii) Likelihood (indicated by cyan highlight), and iii) AIC indicated by (purple highlight). A low RMSE indicates a better fit, the lowest value on the negative likelihood indicates a better fit, and the lowest value on the AIC indicates a better fit. In all three cases, the SPFI appears to perform the best. This supports the conclusions drawn from Scenario 1.

Table 5-10. Relative Error of the HRIs based on median values for Scenario 2.

Year = 1982			
FISHERY	**ROM**	**SA**	**SPFI**
Fishery 1	-4%	0%	1%
Fishery 2	0%	1%	2%
Fishery 3	0%	0%	0%
Fishery 4	0%	0%	0%
Year = 1983			
Fishery 1	3%	0%	-1%
Fishery 2	0%	-1%	-1%
Fishery 3	0%	0%	0%
Fishery 4	0%	0%	0%
Year = 1985			
Fishery 1	-9%	6%	-2%
Fishery 2	-9%	1%	-1%
Fishery 3	-2%	7%	0%
Fishery 4	-2%	8%	-2%
Year = 1986			
Fishery 1	-11%	3%	-3%
Fishery 2	-7%	1%	-2%
Fishery 3	-2%	6%	0%
Fishery 4	-2%	9%	-3%
Year = 1991			
Fishery 1	-10%	2%	-4%
Fishery 2	-9%	0%	-2%
Fishery 3	-2%	7%	0%
Fishery 4	-2%	10%	-2%
Year = 1992			
Fishery 1	-11%	3%	-3%
Fishery 2	-11%	-2%	-2%
Fishery 3	-2%	6%	0%
Fishery 4	-1%	12%	-2%
Average	-2.4%	1.1%	-1.8%

Table 5-11. Overall side by side comparisons for three fisheries between ROM, SA and SPFI for Scenario 2.

SPFI				ROM				SA			
FISHERY	**RMSE**	**Likelihood**	**AIC**	**FISHERY**	**RMSE**	**Likelihood**	**AIC**	**FISHERY**	**RMSE**	**Likelihood**	**AIC**
Year = 1982				Year = 1982				Year = 1982			
Fishery 1	0.00015	-468	-706	Fishery 1	0.00023	-361	-646	Fishery 1	0.00017	-432	-787
Fishery 2	0.00016	-448	-710	Fishery 2	0.00022	-370	-678	Fishery 2	0.00017	-437	-811
Fishery 3	0.00006	-693	-1197	Fishery 3	0.00022	369	-675	Fishery 3	0.00018	-426	-789
Fishery 4	0.00007	-654	-1118	Fishery 4	0.00021	-382	-701	Fishery 4	0.00018	-422	-780
Year = 1983				Year = 1983				Year = 1983			
Fishery 1	0.00015	-468	-706	Fishery 1	0.00023	-361	-646	Fishery 1	0.00017	-432	-787
Fishery 2	0.00016	-448	-710	Fishery 2	0.00022	-370	-678	Fishery 2	0.00017	-437	-811
Fishery 3	0.00006	-693	-1197	Fishery 3	0.00022	-369	-675	Fishery 3	0.00018	-426	-789
Fishery 4	0.00007	-654	-1118	Fishery 4	0.00021	-382	-701	Fishery 4	0.00018	-422	-780
Year = 1985				Year = 1985				Year = 1985			
Fishery 1	0.00017	-430	-630	Fishery 1	0.00041	-212	-348	Fishery 1	0.00046	-187	-297
Fishery 2	0.00017	-431	-676	Fishery 2	0.00041	-213	-363	Fishery 2	0.00042	-207	-352
Fishery 3	0.00005	-742	-1296	Fishery 3	0.00038	-236	-409	Fishery 3	0.00047	-183	-303
Fishery 4	0.00012	-523	-855	Fishery 4	0.0004	-219	-376	Fishery 4	0.00054	-144	-224
Year = 1986				Year = 1986				Year = 1986			
Fishery 1	0.00017	-434	-639	Fishery 1	0.00042	-208	-339	Fishery 1	0.00045	-194	-312
Fishery 2	0.00022	-368	-549	Fishery 2	0.00041	-214	-366	Fishery 2	0.00049	-171	-280
Fishery 3	0.00006	-714	-1239	Fishery 3	0.00041	-215	-367	Fishery 3	0.00049	-168	-273
Fishery 4	0.00012	-529	-869	Fishery 4	0.0004	-220	-377	Fishery 4	0.00048	-177	-290
Year = 1991				Year = 1991				Year = 1991			
Fishery 1	0.00021	-382	-535	Fishery 1	0.00039	-229	-381	Fishery 1	0.00033	-270	-464
Fishery 2	0.0003	-296	-405	Fishery 2	0.00038	-231	-400	Fishery 2	0.0003	-289	-517
Fishery 3	0.00005	-742	-1295	Fishery 3	0.00038	-232	-401	Fishery 3	0.00033	-270	-477
Fishery 4	0.0001	-571	-953	Fishery 4	0.00038	-233	-403	Fishery 4	0.0003	-292	-521
Year = 1992				Year = 1992				Year = 1992			
Fishery 1	0.00015	-466	-702	Fishery 1	0.0004	-218	-360	Fishery 1	0.00037	-244	-411
Fishery 2	0.00022	-367	-547	Fishery 2	0.00039	-227	-391	Fishery 2	0.00034	-265	-467
Fishery 3	0.00005	-744	-1299	Fishery 3	0.00039	-230	-397	Fishery 3	0.00038	-232	-401
Fishery 4	0.00012	-517	-845	Fishery 4	0.00038	-232	-400	Fishery 4	0.00034	-265	-467

5.3.9 SPFI with updates to Base data using Scenario 2, Run 2

In order to test the effect of not including tagged stocks in the base period years, we computed the statistic without the stocks that had no base period data (defined as Scenario 2, Run 2). In all fisheries and years the relative error changes (as compared to the SPFI with all data) but are quite comparable (Table 5-12 versus Table 5-9). In some cases the relative errors improved, and in other cases they got worse, but the shape of the distribution (Figure 5-7 versus Figure 5-6) remains very similar. When we compared the MSE, Likelihood and AIC values, the values were almost identical (Table 5-13), and in all cases the SPFI with all stocks (including stocks with no base data, Scenario 2, Run 1) performed marginally better.

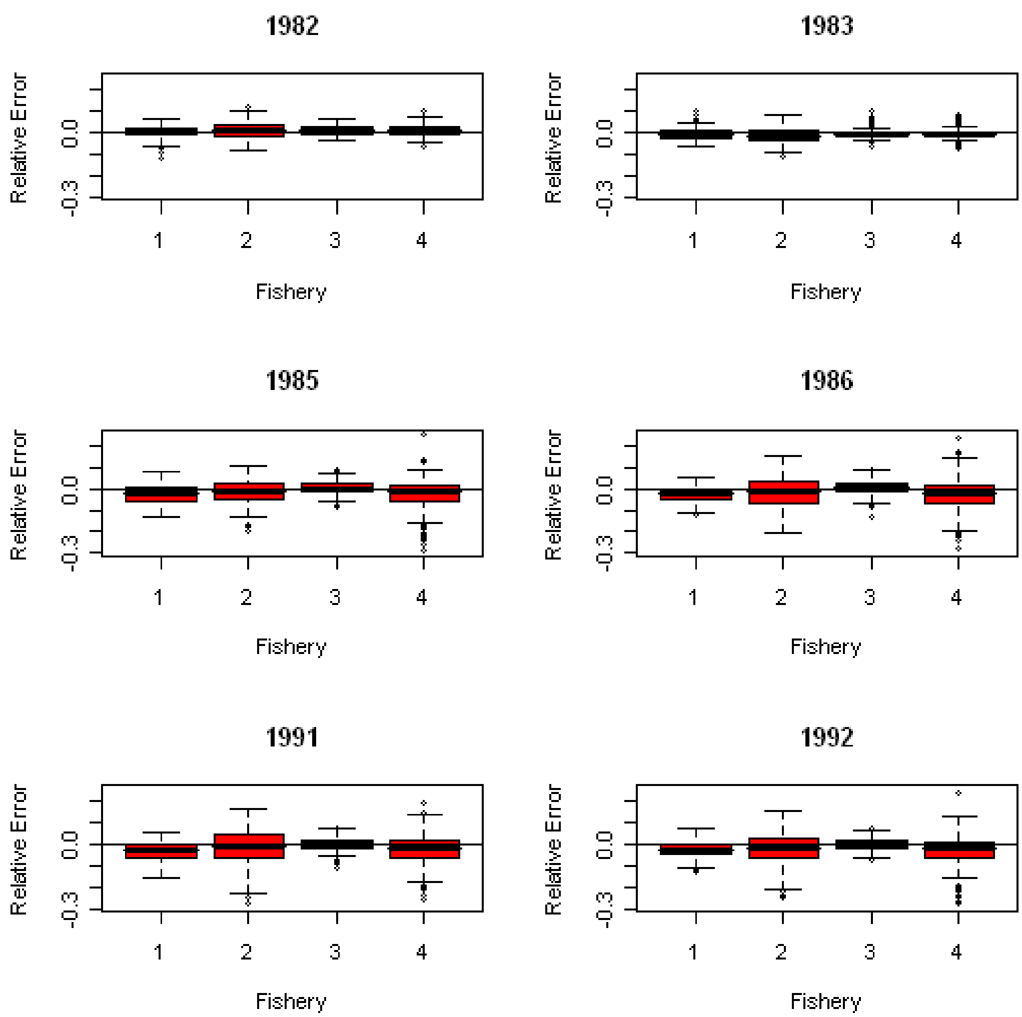


Figure 5-7. SPFI computed without stocks that were not tagged in the base using Scenario 2, Run 2. The x-axis displays the fishery, and the y-axis displays the relative error. The box displays the 25th and 75th quartiles of the relative error distribution, and the whiskers display the 5th and 95th percentiles (i.e. 1.645*the standard error).

Table 5-12. Summary statistics of the relative error distribution for each fishery using SPFI excluding stock without base data for Scenario 2, Run 2.

FISHERY	Min	1st Qt	Median	Mean	3rd Qt	Max
Year = 1982						
Fishery 1	-11%	-1%	1%	1%	2%	7%
Fishery 2	-8%	-2%	1%	1%	4%	12%
Fishery 3	-3%	0%	1%	1%	3%	7%
Fishery 4	-6%	0%	1%	1%	3%	10%
Year = 1983						
Fishery 1	-6%	-2%	-1%	0%	1%	11%
Fishery 2	-11%	-4%	-1%	-1%	1%	8%
Fishery 3	-7%	-1%	-1%	0%	0%	10%
Fishery 4	-7%	-1%	0%	0%	0%	9%
Year = 1985						
Fishery 1	-13%	-6%	-3%	-3%	1%	8%
Fishery 2	-20%	-5%	-1%	-1%	3%	10%
Fishery 3	-9%	-2%	0%	0%	2%	9%
Fishery 4	-29%	-6%	-2%	-3%	1%	25%
Year = 1986						
Fishery 1	-13%	-5%	-3%	-3%	-1%	6%
Fishery 2	-21%	-7%	-2%	-2%	3%	15%
Fishery 3	-13%	-1%	1%	1%	3%	9%
Fishery 4	-28%	-7%	-2%	-3%	2%	23%
Year = 1991						
Fishery 1	-15%	-6%	-3%	-3%	0%	5%
Fishery 2	-27%	-7%	-1%	-2%	5%	17%
Fishery 3	-11%	-1%	0%	0%	2%	8%
Fishery 4	-26%	-6%	-2%	-2%	2%	19%
Year = 1992						
Fishery 1	-13%	-5%	-3%	-3%	0%	7%
Fishery 2	-25%	-6%	-2%	-2%	3%	16%
Fishery 3	-8%	-1%	0%	0%	2%	7%
Fishery 4	-28%	-6%	-2%	-3%	1%	24%

Table 5-13. MSE, Likelihoods and AIC values for different fisheries and time periods for SPFI without base data as compared to the SPFI from all stocks.

SPFI (Scenario 1)				SPFI (Scenario 2)			
FISHERY	**RMSE**	**Likelihood**	**AIC**	**FISHERY**	**RMSE**	**Likelihood**	**AIC**
Year = 1982				Year = 1982			
Fishery 1	0.000149	-468	-706	Fishery 1	0.000149	-468	-714
Fishery 2	0.000161	-448	-710	Fishery 2	0.000162	-446	-719
Fishery 3	0.000061	-693	-1197	Fishery 3	0.000063	-682	-1195
Fishery 4	0.000071	-654	-1118	Fishery 4	0.000072	-649	-1128
Year = 1983				Year = 1983			
Fishery 1	0.00015	-468	-706	Fishery 1	0.000149	-468	-714
Fishery 2	0.00016	-448	-710	Fishery 2	0.000162	-446	-719
Fishery 3	0.00006	-693	-1197	Fishery 3	0.000063	-682	-1195
Fishery 4	0.00007	-654	-1118	Fishery 4	0.000072	-649	-1128
Year = 1985				Year = 1985			
Fishery 1	0.00017	-430	-630	Fishery 1	0.000176	-427	-624
Fishery 2	0.00017	-431	-676	Fishery 2	0.000176	-427	-667
Fishery 3	0.00005	-742	-1296	Fishery 3	0.000049	-746	-1302
Fishery 4	0.00012	-523	-855	Fishery 4	0.000124	-513	-836
Year = 1986				Year = 1986			
Fishery 1	0.00017	-434	-639	Fishery 1	0.000174	-430	-630
Fishery 2	0.00022	-368	-549	Fishery 2	0.000227	-363	-539
Fishery 3	0.00006	-714	-1239	Fishery 3	0.000057	-707	-1224
Fishery 4	0.00012	-529	-869	Fishery 4	0.000128	-505	-820
Year = 1991				Year = 1991			
Fishery 1	0.00021	-382	-535	Fishery 1	0.000214	-378	-526
Fishery 2	0.00030	-296	-405	Fishery 2	0.0003	-293	-400
Fishery 3	0.00005	-742	-1295	Fishery 3	0.000051	-737	-1285
Fishery 4	0.00010	-571	-953	Fishery 4	0.000105	-555	-921
Year = 1992				Year = 1992			
Fishery 1	0.00015	-466	-702	Fishery 1	0.000153	-461	-693
Fishery 2	0.00022	-367	-547	Fishery 2	0.000231	-358	-530
Fishery 3	0.00005	-744	-1299	Fishery 3	0.000052	-733	-1277
Fishery 4	0.00012	-517	-845	Fishery 4	0.00013	-503	-816

5.4 Recommendations

5.4.1 Summary of Scenario 1 and 2 Results

After numerous runs and different algorithms testing stock distribution changes, and fishery structure changes, it appears that the SPFI captures the dynamics of the fisheries most accurately. The following could be concluded from the present analysis:

1. The indices are sensitive to time area changes in fisheries.
2. The SPFI appears to capture these changes most accurately.
3. The ROM appears to overestimate the true index whereas the SA and SPFI appear to underestimate the true measure of fishery intensity as measured by the gauntlet statistic.
4. Regardless of harvest rate (Scenario 1 and Scenario 2), the SPFI appears to capture the true measure of intensity over time more accurately and with the least amount of bias over all scenarios.
5. SPFI with all tag data (including stocks that were not tagged in the base) performs marginally better than SPFI excluding these data in the calculations.

We summarize these results in order of rank in the subsequent Tables (Table 5-14 and Table 5-15). In all cases (other than AIC in Fishery 1 and Year 1982) the SPFI had the highest rank; i.e. outperformed the ROM or the SA on every metric. However, as noted before (Table 5-5 and Table 5-10) the SPFI and ROM median values appear to underestimate the true value, whereas the SA tends to overestimate this value, though confidence intervals do cross 0 indicating no systematic bias (this is probably due to the small sample size used).

5.4.2 Conclusions

An extensive analysis has been performed over the last year. The first phase looked at the effects of a limited number of simulations, and did not change the harvest rates across areas, times and periods. The second phase increased the number of simulations, and dealt with a decrease in harvest rates after the base period with time area changes in fisheries. The SPFI was found to be the most accurate and unbiased estimator in most fisheries, time and areas. Both the ROM and SA seem to capture the overall dynamics over time but may be biased high (ROM) and low (SA) when we have changes in time area fishery effort, and/or catch distributions. Based on these results, we recommend that the SPFI be used in all AABM fisheries to accurately estimate fishery harvest rate impacts. For ISBM fisheries, the ISBM index is the preferred metric when looking at the harvest rate impact on individual stocks across ISBM fisheries. However, the SPFI is the preferred metric for looking at the harvest rate impacts across the stocks in a mixed stock ISBM fishery.

Table 5-14. Rank of the statistic based on fishery and year combinations in Scenario 1. Highlighted cells indicate the best index within a row (by statistic). A 1 indicates the best rank. Average rank over all years and fisheries (a column) are computed at the bottom for each index and statistic.

SPFI				ROM				SA			
FISHERY	**RMSE**	**Likelihood**	**AIC**	**FISHERY**	**RMSE**	**Likelihood**	**AIC**	**FISHERY**	**RMSE**	**Likelihood**	**AIC**
Year = 1982				Year = 1982				Year = 1982			
Fishery 1	1	1	2	Fishery 1	3	3	3	Fishery 1	2	2	1
Fishery 2	1	1	1	Fishery 2	3	3	3	Fishery 2	2	2	2
Fishery 3	1	1	1	Fishery 3	2	2	2	Fishery 3	3	3	3
Fishery 4	1	1	1	Fishery 4	2	2	2	Fishery 4	3	3	3
Year = 1983				Year = 1983				Year = 1983			
Fishery 1	1	1	2	Fishery 1	3	3	3	Fishery 1	2	2	1
Fishery 2	1	1	1	Fishery 2	3	3	3	Fishery 2	2	2	2
Fishery 3	1	1	1	Fishery 3	2	2	2	Fishery 3	3	3	3
Fishery 4	1	1	1	Fishery 4	2	2	2	Fishery 4	3	3	3
Year = 1985				Year = 1985				Year = 1985			
Fishery 1	1	1	1	Fishery 1	3	3	3	Fishery 1	2	2	2
Fishery 2	1	1	1	Fishery 2	3	3	3	Fishery 2	2	2	2
Fishery 3	1	1	1	Fishery 3	2	2	2	Fishery 3	3	3	3
Fishery 4	1	1	1	Fishery 4	2	2	2	Fishery 4	3	3	3
Year = 1986				Year = 1986				Year = 1986			
Fishery 1	1	1	1	Fishery 1	2	2	2	Fishery 1	3	3	3
Fishery 2	1	1	1	Fishery 2	3	3	3	Fishery 2	2	2	2
Fishery 3	1	1	1	Fishery 3	2	2	2	Fishery 3	3	3	3
Fishery 4	1	1	1	Fishery 4	2	2	2	Fishery 4	3	3	3
Year = 1991				Year = 1991				Year = 1991			
Fishery 1	1	1	1	Fishery 1	3	3	3	Fishery 1	2	2	2
Fishery 2	1	1	1	Fishery 2	3	3	3	Fishery 2	2	2	2
Fishery 3	1	1	1	Fishery 3	2	3	3	Fishery 3	3	2	2
Fishery 4	1	1	1	Fishery 4	2	3	3	Fishery 4	3	2	2
Year = 1992				Year = 1992				Year = 1992			
Fishery 1	1	1	1	Fishery 1	2	2	2	Fishery 1	3	3	3
Fishery 2	1	1	1	Fishery 2	3	3	3	Fishery 2	2	2	2
Fishery 3	1	1	1	Fishery 3	2	2	2	Fishery 3	3	3	3
Fishery 4	1	1	1	Fishery 4	2	2	2	Fishery 4	3	3	3

Table 5-15. Rank of the statistic based on fishery and year combinations in Scenario 2 Run 1. Highlighted cells indicate the best index within a row (by statistic). A 1 indicates the best rank. Average rank over all years and fisheries (a column) are computed at the bottom for each index and statistic.

SPFI				ROM				SA			
FISHERY	**RMSE**	**Likelihood**	**AIC**	**FISHERY**	**RMSE**	**Likelihood**	**AIC**	**FISHERY**	**RMSE**	**Likelihood**	**AIC**
Year = 1982				Year = 1982				Year = 1982			
Fishery 1	1	1	2	Fishery 1	3	3	3	Fishery 1	2	2	1
Fishery 2	1	1	2	Fishery 2	3	3	3	Fishery 2	2	2	1
Fishery 3	1	1	1	Fishery 3	3	3	3	Fishery 3	2	2	2
Fishery 4	1	1	1	Fishery 4	3	3	3	Fishery 4	2	2	2
Year = 1983				Year = 1983				Year = 1983			
Fishery 1	1	1	2	Fishery 1	3	3	3	Fishery 1	2	2	1
Fishery 2	1	1	2	Fishery 2	3	3	3	Fishery 2	2	2	1
Fishery 3	1	1	1	Fishery 3	3	3	3	Fishery 3	2	2	2
Fishery 4	1	1	1	Fishery 4	3	3	3	Fishery 4	2	2	2
Year = 1985				Year = 1985				Year = 1985			
Fishery 1	1	1	1	Fishery 1	2	2	2	Fishery 1	3	3	3
Fishery 2	1	1	1	Fishery 2	2	2	2	Fishery 2	3	3	3
Fishery 3	1	1	1	Fishery 3	2	2	2	Fishery 3	3	3	3
Fishery 4	1	1	1	Fishery 4	2	2	2	Fishery 4	3	3	3
Year = 1986				Year = 1986				Year = 1986			
Fishery 1	1	1	1	Fishery 1	2	2	2	Fishery 1	3	3	3
Fishery 2	1	1	1	Fishery 2	2	2	2	Fishery 2	3	3	3
Fishery 3	1	1	1	Fishery 3	2	2	2	Fishery 3	3	3	3
Fishery 4	1	1	1	Fishery 4	2	2	2	Fishery 4	3	3	3
Year = 1991				Year = 1991				Year = 1991			
Fishery 1	1	1	1	Fishery 1	3	3	3	Fishery 1	2	2	2
Fishery 2	1	1	2	Fishery 2	3	3	3	Fishery 2	2	2	1
Fishery 3	1	1	1	Fishery 3	3	3	3	Fishery 3	2	2	2
Fishery 4	1	1	1	Fishery 4	3	3	3	Fishery 4	2	2	2
Year = 1992				Year = 1992				Year = 1992			
Fishery 1	1	1	1	Fishery 1	3	3	3	Fishery 1	2	2	2
Fishery 2	1	1	1	Fishery 2	3	3	3	Fishery 2	2	2	2
Fishery 3	1	1	1	Fishery 3	3	3	3	Fishery 3	2	2	2
Fishery 4	1	1	1	Fishery 4	3	3	3	Fishery 4	2	2	2
Avg Rank	1	1	1.21		2.7	2.7	2.7		2.3	2.3	2.1

Chapter 6. Implications of adopting a new HRI metric

6.1 Background

Under the 1999 PSC Chinook Agreement, AABM fishery regimes were developed that were intended to adjust fishery harvest rates relative to the base period (1979-1982) levels in response to changes in the aggregate abundance of stocks represented in the PSC Chinook Model (referred to as Model hereafter). The AABM regimes were constructed for each AABM fishery by defining a historical relationship (1979-1997) between the yearly Model Abundance Indices (AIs), observed catch levels in the associated troll fishery and the troll fishery HRIs derived from the CWT-based Chinook ER Analysis. Table 1 of Annex IV, Chapter 3 of the Pacific Salmon Treaty between the Government of Canada and the Government of the United States of America (hereafter referred to as Table 1) reflects the resulting inter-relationships between the AIs, HRIs and catches that were negotiated for the three AABM fisheries (CTC Technical Note, 2003).

Mechanically, allowable catches in the AABM fisheries are determined annually after calibration of the Model. The yearly Model calibration incorporates updates to historic catch, terminal run and escapement estimates, results of CWT-based ER analysis, and stock specific abundance forecasts for the coming year. After the Model is calibrated, Abundance Indices (AIs) for the SEAK, NBC, and WCVI troll fisheries are computed. Annual allowable catches for the three AABM fisheries are determined by the fishery specific catch levels associated with these AIs contained in Table 1 of the agreement. These catch levels are designed to achieve a target HRI level that is also contained in Table 1 of the agreement.

In 2007, a CTC Support Group was tasked with evaluating alternative metrics to measure HRIs and recommending the metric that most accurately reflects true fishery harvest rates. If the PSC adopts a new HRI and employs mechanisms for implementation of AABM regimes which are analogous to those incorporated into the 1999 Agreement, three broad areas would be affected: (1) Establishing Table 1 catch constraints; (2) Implementation - annual determination of allowable catch (mortality) constraints for AABM fisheries; and (3) Monitoring performance.

6.2 Establishing Table 1 catch constraints

The AABM catch levels represented in Table 1 of the 1999 PST Agreement depend on three factors: (a) the negotiated HRIs at given AI levels; (b) the historic data and relationships between the troll catches, HRIs and AIs for the historical time period (1979-1995); and (c) assumptions regarding the allocation of catch among fishing sectors (Troll, Sport and Net). Changes to any of these factors would affect Table 1. For purposes of this section, only (b) and (c) will be addressed.

The catch ceilings depicted in Table 1 are intended to constrain fishery harvest rates in response to changes in aggregate stock abundance as reflected by an abundance index (AI) estimated by the Model. Procedures to calculate an AI are described in "Notes on Index Development – AWG" (CTC AWG, 1989) and in TCCHINOOK (1997). The CTC abundance index is simply the ratio between the expected catch in the year of interest under base period exploitation patterns and the estimated catch during the 1979-1982 base period. In mathematical form, the AI for a given fishery and year is computed as follows:

$$AI_{f,y} = \frac{\sum_{s}\sum_{a} COH_{y,s,a} * bpER_{f,s,a} * (1 - PNV_{f,a})}{\left(\frac{\sum_{b=1979}^{1982} \sum_{s}\sum_{a} COH_{b,s,a} * bpER_{f,s,a} * (1 - PNV_{f,a})}{4} \right)} \qquad (6\text{-}1)$$

where the numerator is the expected catch in the fishery in year *y* given the stock-age cohort sizes in year y under base period exploitation rates and the denominator is the average catch in the fishery during the base period.

The AI only reflects the relative abundance for the stocks that are included in the PSC Chinook Model. Since not all stocks are fully represented, this index may not reflect changes in total abundance if the proportion of the stocks that are not included in the model changes significantly over time. Further, the AI assumes that fishing and stock distribution and migration patterns remain relatively stable.

When the 1999 Agreement was negotiated, the troll sectors included under AABM regimes were presumed to account for a fixed, major proportion of the total AABM catch. This presumption was critical to the ability to attain the desired HRI. Under a new Agreement, different sector allocations could be employed, but development of a new Table 1 would be more complex because impacts of each sector would need to be considered separately and then combined. Extensive documentation of assumptions, data, procedures and methods would be advised to provide a common basis of understanding.

The Chinook catch for the troll sector of an AABM fishery complex can be computed for any value of the abundance index and a target harvest rate (*HRItar*) negotiated for the 1999 Agreement.

$$C = e^{(K + LN(HRItar * AI))} \qquad (6\text{-}2)$$

where K is a proportionality constant

The total catch for the total AABM fishery complex is then calculated by incorporating additional gear allocations relative to the troll catch. For SEAK, this was done by assuming that the sport catch equals 25% of the troll catch and that the net catch would be 20,000 fish[4]:

$$TotalSEAKAABMCeiling = (TrollCeiling / 0.8) + 20{,}000 \qquad (6\text{-}3)$$

[4] The all gear catch is currently allocated as follows: Seine 4.3%; Drift Gillnet 2.9%; Set Gillnet 1,000; Troll and Sport share 80%/20% of total AABM catch minus net allocation. Actual allocations may change by Alaska Board of Fisheries action.

The total catch at any given AI can be calculated for each of these fisheries by using the appropriate combination of proportionality constant and *HRItar*. For example, if the AI for the SEAK troll fishery is 1.5, the *HRItar* is 0.60 and the allowable all gear catch is computed as:

$$TotalSEAKAABMCeiling = (e^{(12.38 + LN(0.60*1.50))} / 0.8) + 20000 = 287{,}743 \qquad (6\text{-}4)$$

For NBC and WCVI fisheries, the sport catch was assumed to be 25% of the allowable troll catch.[5] Therefore, the total catch allowable for these AABM fishery complexes was computed as:

$$TotalNBC(WCVI)Ceiling = (TrollCeiling / 0.8) \qquad (6\text{-}5)$$

The proportionality constant (K) used to construct Table 1 of the 1999 Agreement is estimated as the arithmetic mean of the annual estimates of K during the selected base period using the following linear transformation of equation (6-2):

$$\begin{aligned} LN(C_y) &= K_y + LN(HRItar_y * AI_y) \\ K_y &= LN(C_y) - LN(HRItar_y * AI_y) \end{aligned} \qquad (6\text{-}6)$$

where *y* refers to the year

A time series of AIs is generated whenever the Model is calibrated. The values in this time series can change as a result of data updates (e.g., escapements, terminal run sizes, estimates of exploitation or maturity rates, etc.), the development of new base period data sets involving revised CWT recovery data or different stock or fishery stratification, or selection of a different base period or size limits.

HRIs are generated through ER analyses of CWT release and recovery data. Estimates of exploitation and maturation rates for incomplete broods typically change over time as more data become available. HRIs can also change due to modification of CWT recovery and catch sample data, new methods for performing cohort analyses (e.g., estimation of incidental fishing mortality loss, consideration of stock-specific growth functions).

Catch data are provided by management agencies. Estimates of historic catches can change in response to a variety of factors, such as adjustments for average weights, changes in stratifications employed for catch estimation, corrections for hail estimates or missing or incomplete data.

Interrelationships between catch, fishery HRIs and model AIs is readily apparent in equation (6-6). Proportionality constants which relate HRIs, AIs, and observed catch will change when HRI, catches, or abundance indices change or when the period employed to define inter-relationships is altered. The Appendix to Assignment 2, particularly the section titled *"Restructuring the*

[5] Within the total allowable AABM catch, the recreational fishery has priority allocation and may not be limited to the assumed 25% of the troll catch.

Relationship Among Catch, AIs, and FIs", at pages 43-48 of the CTC Small Workgroup report (2007) describes how Table 1 catches would be affected by changes in HRIs.

6.3 Implementation for Annual Determination of Allowable Catch

The time series of HRIs and AIs implicitly reflect impacts of fisheries which occurred during the selected time period used to estimate the Ks used to construct Table 1 of the 1999 Agreement. Presuming that a mechanism analogous to Table 1 is incorporated into the new agreement as a means to effectuate negotiated HRI-AI relationships for AABM regimes, if fishing patterns and sector allocations are expected to be stable and consistent with the assumptions employed to develop Table 1, the allowable catch could simply be determined by looking up the value associated with a given AI.

Alternatively, if AABM fisheries are to be conducted in a manner that differs from that assumed in Table 1, the allowable catch would be derived using pre-defined adjustment procedures. The High Priority CTC Small Group Assignments Report (CTC Small Group, 2007) presented two examples of alternative ways of determining allowable catch. Option A (pages 6-11) in Assignment 1 of that report describes a method of adjusting the proportionality constant using a catch scalar to adjust the AABM TAC when fishing patterns deviate from those used to establish the values in Table 1. Assignment *5 "Effectiveness of Establishing Catch Ceilings Based on Abundance Indices Computed Using Expected Fishing Patterns in Achieving Target Fishery Harvest Rates"* at pages 59-64 of the CTC Small Workgroup report (2007) describes a Catch Pattern Scalar (CPS) approach for establishing catch ceilings, including an example of how sector (troll-sport) allocations could be handled.

If stability in fishing patterns and sector allocations are not anticipated, consideration should be given to replacing Table 1 by pre-defined methods and procedures for establishing AABM constraints.

6.3.1 Implementation of SPFI

Stratum specific HRI values can be incorporated in the Model as Fishery Policy (FP) scalars that scale the base period ERs by year, stock, and age for the fishery of interest. The incorporation of strata specific SPFI index values into the Chinook model FP file is already being done for the Alaska troll fishery.

Converting the strata specific HRI values into FP values requires scaling the base period ERs by stock and age that are currently contained in the Model STK file[6]. The first step in this process is to divide the base period stock and age specific ERs into strata specific rates by multiplying them by the proportion of the estimated base period CWT recoveries of that stock and age that occurred in each stratum. This produces stratified base period ERs by stock and age. The stratified base period ERs are then multiplied by the corresponding strata specific HRIs by year. This produces estimates of current ERs by stock, age and year. These in turn are divided by the corresponding stock and age specific base period ERs from the STK file to produce year, stock,

[6] The Model STK file includes information on the Model stocks including initial abundances and base period exploitation rates.

and age specific FP scalars for the fishery of interest. The FP scalars are then incorporated in to the Model FPA files that are combined with other input data to produce Model catch estimates.

6.3.1.1 NBC SPFI

After reviewing the historic distribution of catch both spatially and temporally in the NBC troll fishery, we determined that there was no feasible stratification other than a complete year and area-wide stratum due to inadequate catches in certain times and areas that would create large gaps in the yearly strata specific information. Therefore, it was determined that a SPFI was still possible for the NBC troll fishery but that it would consist of only one yearly stratum. Although having only one stratum defeats some of the impetus for computing a stratified estimator like the SPFI, there is another reason why computing a SPFI for NBC might be preferred to computing the SA or ROM HRI. The formulation of the SPFI allows for the separation of the distributional aspects of the stocks and ages to arrive at an estimate the harvest rate in the fishery, whereas the SA or ROM HRI estimators are based upon indices of ERs as opposed to harvest rates.

Table 6-1 contains the estimated AEQ landed catch SPFI values for the NBC troll fishery from 1979 to 2005 using a single yearly stratum. The stocks and ages used for the NBC SPFI are those stocks and ages that meet or exceed the long-term average (through 1995) of 35 estimated recoveries (Table 6-2). This same criterion is currently used in the ROM HRI for both NBC and WCVI. The ROM HRI as it is currently implemented in the ER analysis also has a second criterion that the predicted recoveries for a stock and age in any particular year must be at least half of the long-term average recoveries. In other words, the predicted recoveries in a year would need to be greater than or equal to 0.5*35 = 17.5. If this second criterion is not met then the ER for that stock-age combination is not used in the calculation of the ROM HRI for that year. However, this second criterion is not applied to the SPFI estimator.

As stated earlier, the SPFI estimator has the ability to incorporate stocks and ages even if these stocks and ages are not present in the base period. This is another advantage of the SPFI over the SA or ROM estimators, although this advantage is currently not being utilized due to the criterion that is being used to select the stocks and ages for inclusion in the SPFI.

Table 6-1. NBC landed catch SPFI values from 1979 to 2005 (AEQ).

YEAR	**SPFI**
1979	0.90
1980	0.90
1981	1.31
1982	0.90
1983	0.93
1984	0.85
1985	0.82
1986	0.75
1987	0.75
1988	0.61
1989	0.65
1990	0.55
1991	0.60
1992	0.43
1993	0.48
1994	0.60
1995	0.25
1996	0.00
1997	0.22
1998	0.41
1999	0.17
2000	0.06
2001	0.06
2002	0.14
2003	0.20
2004	0.24
2005	0.34

Table 6-2. Stocks and ages that met criteria for inclusion in NBC SPFI.

Stock	**Ages**		
Alaska Southeast	4		
Quinsam	3	4	
Robertson Creek	3	4	5
Salmon River Hatchery	3	4	5
Columbia Upriver Brights	3	4	5
Willamette Spring Hatchery	4		

6.3.1.2 WCVI SPFI

After reviewing the time-series of catch information for the WCVI troll fishery, three temporal strata were identified to provide adequate representation of the temporal shifts that have occurred in the timing of the catch in the WCVI troll fishery while at the same time providing for adequate catch levels in most instances. Only three temporal strata were used to construct a SPFI for the WCVI troll fishery. Spatial stratification, such as by north and south, was not appropriate because CWT recovery data were too sparse in the north to be informative.

The three temporal strata that were identified are as follows: October to April, May to June, and July to September. Note that the first strata identified spans across calendar years. This is due to the fact that all AABM troll fisheries operate on an accounting year that runs from October through September.

The strata specific Chinook catches for the WCVI troll fishery are presented in Table 6-3. One thing that is readily apparent is the lack of harvest in some strata during certain years. This causes a problem in the calculation of the SPFI as mentioned previously for years in which there is either no catch in a stratum or the catch is so small that it results in no CWT recoveries. This problem is readily apparent by looking at Equation 4-13 of the SPFI formulation presented in section 4.1.4. The term in the denominator of this equation, $\sum_x \hat{C}_{f,y,x} / cwtHR_{f,y,x} = \hat{N}_{f,y}$, which would be the total yearly abundance is the sum of the estimated yearly abundances for all strata and it contains both the strata specific catch estimates and the CWT harvest rate estimates for each strata. If there is no catch in a stratum or no CWT recoveries, the abundance in that stratum cannot be estimated due to a division by zero. This in turn prevents the calculation of the HRI, and therefore the SPFI, for the years in which this situation exists. The total yearly abundance must then be estimated using alternate means. The Average Proportion Correction (APC) method described in Appendix 5 (Bootstrap analysis) was the method chosen to address this problem in the actual WCVI troll fishery data.

Table 6-3. Chinook catches by strata for the WCVI troll fishery from 1979 to 2005.

Catch Year	Oct-Apr	May-June	July-Sept	Total
1979	84,558	187,612	211,377	483,547
1980	72,882	193,090	219,202	485,174
1981	64,212	130,351	219,417	413,980
1982	60,261	195,496	289,524	545,281
1983	57,649	122,280	207,619	387,548
1984	35,864	112,429	319,101	467,394
1985	0	59,699	291,347	351,046
1986	3,069	80,569	261,818	345,456
1987	0	19	378,940	378,959
1988	0	611	408,057	408,668
1989	68	1,390	202,327	203,785
1990	153	6,566	291,254	297,973
1991	0	7,929	194,988	202,917
1992	6,130	4,348	333,237	343,715
1993	3,027	0	272,366	275,393
1994	2,382	0	145,929	148,311
1995	0	379	80,878	81,257
1996	0	0	4	4
1997	0	1,542	50,844	52,386
1998	1,246	925	7	2,178
1999	5,511	0	0	5,511
2000	57,401	3,828	0	61,229
2001	41,021	20,355	14,188	75,564
2002	36,573	89,012	8,606	134,191
2003	55,726	96,850	6	152,582
2004	102,460	34,776	32,335	169,571
2005	99,926	26,655	16,874	143,455

For the application of the APC method, abundance estimates for all years in which all three strata had recorded catches were used to estimate the average percentage of the total yearly abundance that occurred in each stratum. The total yearly abundance was then estimated by dividing the sum of the abundances from the strata that could be estimated by the average percent of the total yearly abundance that these strata comprise. The total yearly abundance estimate was then substituted into the denominator of Equation 4-13 to produce the yearly HRI estimate which in turn was used in the calculation of the yearly SPFI estimate (Equation 4-15). The AEQ landed catch WCVI SPFI estimates for the years 1979 to 2005 are presented in Table 6-4 and the stock and ages that met the minimum criteria (average of 35 recoveries) in Table 6-5.

Table 6-4. WCVI Landed Catch SPFI Values from 1979 to 2005 (AEQ).

YEAR	SPFI	FALL/WIN	SPRING	SUMMER
1979	1.07	1.15	1.08	0.99
1980	1.16	0.95	1.30	1.13
1981	0.87	1.38	0.71	0.82
1982	0.89	0.52	0.91	1.05
1983	0.94	1.12	0.73	0.99
1984	1.41	0.98	1.01	1.67
1985	0.91	0.00	0.50	1.45
1986	0.93	0.12	0.47	1.31
1987	0.79	0.00	0.00	1.47
1988	0.96	0.00	0.00	1.79
1989	0.49	0.00	0.00	0.92
1990	0.81	0.00	0.05	1.70
1991	0.42	0.00	0.03	1.13
1992	1.26	0.23	0.00	2.00
1993	0.86	0.04	0.00	2.00
1994	0.53	0.04	0.00	1.17
1995	0.35	0.00	0.00	0.66
1996	0.00	0.00	0.00	0.00
1997	0.22	0.00	0.00	0.41
1998	0.01	0.01	0.05	0.00
1999	0.04	0.24	0.00	0.00
2000	0.28	1.82	0.05	0.00
2001	0.18	0.56	0.37	0.05
2002	0.20	0.22	0.71	0.02
2003	0.24	0.49	0.60	0.00
2004	0.25	1.17	0.47	0.07
2005	0.50	2.27	0.37	0.10

Table 6-5. Stocks and ages that met criteria for inclusion in WCVI SPFI (AEQ).

Stock	**Ages**			**Stock**	**Ages**		
Cowlitz Fall Tule	4			South Puget Sound Fingerling	3	4	
George Adams	3	4		Salmon River Hatchery	3	4	5[7]
Lower River Hatchery	3	4		Columbia River Summers	4		
Lewis River Wild	4			Columbia Upriver Brights	3	4	
Robertson Creek	3	4	5	University of Washington	3	4	
Samish	3	4		Willamette Spring Hatchery	4		
Spring Creek	3	4		Chilliwack	3[7]	4[7]	

[7] Salmon River Hatchery Age 5 fish and Chilliwack Age 3 and 4 fish have long-term average recoveries that are at least 35 fish so they are included in the calculation of the SPFI. However, there are no 1979-1982 base period recoveries of these stock-age combinations so they are not present in the ROM index for the WCVI Troll fishery.

Table 6-6 contains the CWT harvest rates, the AEQ catches and the abundances for all three strata in the WCVI troll fishery from 1979 to 2005. In addition, it also contains a Strata Flag that indicates if particular strata are present or missing. The Strata Flag consists of three digits that are either 0 or 1 depending on whether the catch is missing or present for strata one through three. For instance, years with Strata Flags of 111 have catches in all three strata, and years with Strata Flags of 011 are missing catch in the first stratum, and so on. Note that the strata specific abundances that correspond to strata with missing catches are listed as NA to indicate that the abundance estimates cannot be calculated for these strata. The average percent of the total yearly abundance accounted for by each strata was estimated using all years with a Strata Flag of 111 (catch present in all three strata). This occurred in the following years: 1979-1984, 1986, 2001-2002 and 2004-2005. The abundances from these years were summed across years within each stratum. Each stratum specific total from this summation was then divided by the sum of the three strata specific totals to produce an estimate of the average percent of the total yearly abundance that each stratum represented. The Scalar represents the average percentage of the total yearly abundance that can be accounted for by the strata with non-zero catches in the year of interest.

More specifically: For the years (y = 1979-1984, 1986, 2001-2002, 2004-2005) where each of the three strata (x = 1 to 3) contain Chinook catches of sufficient size ($\geq$ 1,000 fish) to produce reliable CWT contribution estimates, the following SPFI calculations were made:

$$N_{f,y} = \sum_{x} C_{f,y,x} / cwtHR_{f,y,x} \quad (6.7)$$

$$HR_{f,y} = \frac{\sum_{x}\left[\left(\frac{\sum_{s}\sum_{a} aeqCWT_{f,y,s,a,x}}{\sum_{s}\sum_{a} CWT_{f,y,s,a,x}}\right) * C_{f,y,x}\right]}{N_{f,y}} \quad (6.8)$$

$$SPFI_{f,y} = \frac{HR_{f,y}}{\left(\frac{\sum_{b=1979}^{1982} HR_{f,b}}{4}\right)} \quad (6.9)$$

and the APC was calculated as follows:

$$N_{f,x} = \sum_{y} C_{f,y,x} / cwtHR_{f,y,x} \quad (6.10)$$

$$N_{f} = \sum_{x} N_{f,x} = \sum_{y}\sum_{x} C_{f,y,x} / cwtHR_{f,y,x} \quad (6.11)$$

$$APC = \overline{P_{f,x}} = \frac{N_{f,x}}{N_f} = \frac{\sum_y \left(C_{f,y,x} / cwtHR_{f,y,x} \right)}{\sum_y \sum_x \left(C_{f,y,x} / cwtHR_{f,y,x} \right)} \tag{6.12}$$

For the years (*y* = 1985,1987-2000,2003) where there is at least one stratum (*x*) with a Chinook catch too small (< 1,000 fish) to produce reliable CWT contribution estimates, the following estimated SPFI calculations were made:

$\tilde{N}_{f,y}$ = Estimated total abundance in year y across all strata (estimated total yearly abundance).
$\tilde{HR}_{f,y}$ = Estimated harvest rate in year y.
$\tilde{SPFI}_{f,y}$ = Estimated SPFI in year y.

$$\tilde{N}_{f,y} = \frac{\sum_x N_{f,y,x}}{\sum_x \overline{P_{f,x}}} \tag{6.13}$$

, where the *x*s are all fishery-year-strata combinations with non-zero catches and $\sum_x \overline{P_{f,x}}$ is the APC scalar.

$$\tilde{HR}_{f,y} = \frac{\sum_x \left[\left(\frac{\sum_s \sum_a aeqCWT_{f,y,s,a,x}}{\sum_s \sum_a CWT_{f,y,s,a,x}} \right) * C_{f,y,x} \right]}{\tilde{N}_{f,y}} \tag{6.14}$$

$$\tilde{SPFI}_{f,y} = \frac{\tilde{HR}_{f,y}}{\left(\frac{\sum_{b=1979}^{1982} HR_{f,b}}{4} \right)} \tag{6.15}$$

Table 6-6. Strata specific harvest rates, AEQ catches, abundances, missing Strata Flags, and SPFI harvest rates used in the calculation of the AEQ landed catch SPFI for WCVI.

	CWT HR			AEQ CATCH			ABUNDANCE						
YEAR	**STR 1**	**STR 2**	**STR 3**	**STR 1**	**STR 2**	**STR 3**	**STR 1**	**STR 2**	**STR 3**	**STRATA FLAG**	**SCALAR**	**SPFI HR**	**SPFI**
1979	0.10221	0.19402	0.12302	79,321	174,402	191,369	827,314	966,967	1,718,230	111	1.00000	0.12672	1.07
1980	0.08470	0.22980	0.13809	68,040	181,714	201,782	860,636	840,241	1,587,356	111	1.00000	0.13732	1.16
1981	0.12743	0.13142	0.10362	57,753	117,778	195,294	503,917	991,891	2,117,584	111	1.00000	0.10263	0.87
1982	0.04540	0.16122	0.13175	56,993	184,296	258,870	1,327,556	1,212,632	2,197,452	111	1.00000	0.10557	0.89
1983	0.09660	0.12658	0.11699	55,759	117,828	197,670	596,784	966,043	1,774,743	111	1.00000	0.11124	0.94
1984	0.08880	0.18559	0.20994	32,930	102,144	285,169	403,691	605,791	1,519,951	111	1.00000	0.16614	1.41
1985	0.00000	0.08820	0.17798	0	56,926	265,292	NA	677,128	1,636,972	011	0.77373	0.10773	0.91
1986	0.00998	0.08570	0.16446	3,069	73,699	233,520	307,367	939,950	1,591,939	111	1.00000	0.10928	0.93
1987	0.00000	0.00000	0.18408	0	0	339,696	NA	NA	2,058,587	001	0.56592	0.09338	0.79
1988	0.00000	0.00000	0.21129	0	0	387,782	NA	NA	1,931,300	001	0.56592	0.11363	0.96
1989	0.00000	0.00000	0.11377	0	0	183,422	NA	NA	1,778,409	001	0.56592	0.05837	0.49
1990	0.00000	0.00816	0.20578	0	6,310	269,452	NA	805,038	1,415,369	011	0.77373	0.09609	0.81
1991	0.00000	0.00529	0.13958	0	7,696	177,280	NA	1,499,513	1,396,946	011	0.77373	0.04941	0.42
1992	0.02070	0.00000	0.24419	5,782	0	305,582	296,850	NA	1,364,673	101	0.79219	0.14845	1.26
1993	0.00352	0.00000	0.24709	3,027	0	247,081	858,924	NA	1,102,305	101	0.79219	0.10102	0.86
1994	0.00330	0.00000	0.13738	2,382	0	139,693	721,473	NA	1,062,247	101	0.79219	0.06310	0.53
1995	0.00000	0.00000	0.07800	0	0	76,349	NA	NA	1,036,776	001	0.56592	0.04167	0.35
1996	0.00000	0.00000	0.00000	0	0	0	NA	NA	NA	000	0.00000	0.00000	0.00
1997	0.00000	0.00000	0.04910	0	0	48,039	NA	NA	1,036,198	001	0.56592	0.02624	0.22
1998	0.00115	0.00896	0.00000	1,246	925	0	1,082,015	103,293	NA	110	0.43408	0.00080	0.01
1999	0.02060	0.00000	0.00000	5,399	0	0	267,987	NA	NA	100	0.22627	0.00456	0.04
2000	0.15378	0.00897	0.00000	56,570	3,750	0	373,267	426,797	NA	110	0.43408	0.03273	0.28
2001	0.04910	0.06742	0.00680	38,752	18,731	12,795	836,144	301,900	2,086,008	111	1.00000	0.02180	0.18
2002	0.01924	0.12866	0.00312	34,287	81,722	7,660	1,900,578	691,855	2,758,975	111	1.00000	0.02311	0.20
2003	0.04190	0.10916	0.00000	54,393	89,484	0	1,329,810	887,218	NA	110	0.43408	0.02817	0.24
2004	0.10177	0.08340	0.00816	97,829	32,882	29,577	1,006,737	417,203	3,964,141	111	1.00000	0.02975	0.25
2005	0.19499	0.06540	0.01200	96,548	24,844	15,057	512,480	407,838	1,401,517	111	1.00000	0.05877	0.50

Example 1.

In Table 6-6 the Strata Flag for 1985 is 011 which indicates that there is no catch for strata 1. The harvest rate for 1985 cannot be computed since the yearly harvest rate ($HR_{f,y}$) is a function of the total yearly abundance ($N_{f,y}$) which in turn is a function of the strata specific abundances ($N_{f,y,x}$). Since $N_{f,1985,1}$ (abundance in strata 1 in 1985) cannot be computed this results in the inability to compute $HR_{f,1985}$. Therefore, the APC method is used to resolve this problem and the total yearly abundance ($N_{f,1985}$) is replaced with the estimated total yearly abundance ($\tilde{N}_{f,1985}$). The average percentage of the total yearly abundance in each stratum ($\overline{P_{f,x}}$) based on the years 1979-1984, 1986, 2001-2002, 2004-2005 is as follows:

$\overline{P_{f,1}} = 0.22627$

$\overline{P_{f,2}} = 0.20781$

$\overline{P_{f,3}} = 0.56592$

$$\tilde{N}_{f,1985} = \frac{\sum_{x=2}^{3} N_{f,1985,x}}{\sum_{x=2}^{3} \overline{P_{f,x}}}$$

$$\tilde{N}_{f,1985} = \frac{(677,128.1 + 1,636,972.0)}{(0.20781 + 0.56592)} = \frac{2,314,100.1}{0.77373} = 2,990,836.7$$

$$\tilde{HR}_{f,1985} = \frac{(56,925.70 + 265,291.60)}{2,990,836.7} = 0.10773$$

$$\tilde{SPFI}_{f,1985} = \frac{0.10773}{0.11806} = 1.07$$

6.3.1.3 AEQ vs. Nominal

The SPFI for the SEAK troll fishery has historically been calculated in terms of AEQs. However, in order to investigate the magnitude of the difference between AEQ and nominal SPFI estimates, the WCVI SPFI was calculated in terms of AEQs (Table 6-4 to Table 6-6) and in terms of nominal values (Table 6-7 to Table 6-9). In general, the difference in the yearly AEQ and nominal SPFI values for WCVI was negligible. Typically the AEQ and nominal values were within a few hundredths of each other. This result indicates that this issue deserves more investigation in both the SEAK and NBC fisheries to determine the most appropriate or informative form of the SPFI (AEQ or nominal) for future use.

Table 6-7. WCVI Landed Catch SPFI Values from 1979 to 2005 (Nominal).

YEAR	SPFI	FALL/WIN	SPRING	SUMMER
1979	1.07	1.14	1.08	0.99
1980	1.15	0.94	1.28	1.11
1981	0.89	1.42	0.73	0.83
1982	0.89	0.50	0.90	1.06
1983	0.90	1.07	0.71	0.94
1984	1.44	0.99	1.04	1.69
1985	0.91	0.00	0.49	1.43
1986	0.95	0.11	0.48	1.33
1987	0.81	0.00	0.00	1.48
1988	0.93	0.00	0.00	1.70
1989	0.50	0.00	0.00	0.92
1990	0.81	0.00	0.05	1.66
1991	0.42	0.00	0.03	1.12
1992	1.26	0.23	0.00	1.97
1993	0.86	0.04	0.00	1.99
1994	0.51	0.04	0.00	1.11
1995	0.34	0.00	0.00	0.63
1996	0.00	0.00	0.00	0.00
1997	0.22	0.00	0.00	0.40
1998	0.01	0.01	0.05	0.00
1999	0.04	0.23	0.00	0.00
2000	0.26	1.71	0.05	0.00
2001	0.18	0.55	0.38	0.05
2002	0.19	0.21	0.72	0.03
2003	0.23	0.47	0.61	0.00
2004	0.24	1.13	0.47	0.07
2005	0.48	2.17	0.36	0.10

Table 6-8. Stocks and ages that met criteria for inclusion in WCVI SPFI (Nominal).

Stock	**Ages**			**Stock**	**Ages**		
Cowlitz Fall Tule	4			South Puget Sound Fingerling	3	4	
George Adams	3	4		Salmon River Hatchery	3	4	5[7]
Lower River Hatchery	3	4		Columbia River Summers	4		
Lewis River Wild	4			Columbia Upriver Brights	3	4	
Robertson Creek	3	4	5	University of Washington	3	4	
Samish	3	4		Willamette Spring Hatchery	4		
Spring Creek	3	4		Chilliwack	3[7]	4[7]	

Table 6-9. Strata specific harvest rates, catches, abundances, missing Strata Flags, and SPFI harvest rates used in the calculation of the nominal landed catch SPFI.

YEAR	CWT HR			NOMINAL CATCH			ABUNDANCE			STRATA FLAG	SCALAR	SPFI HR	SPFI
	STR 1	STR 2	STR 3	STR 1	STR 2	STR 3	STR 1	STR 2	STR 3				
1979	0.10221	0.19402	0.12302	84,558	187,612	211,377	827,314	966,967	1,718,230	111	1.00000	0.13766	1.07
1980	0.08468	0.22980	0.13809	72,882	193,090	219,202	860,636	840,241	1,587,356	111	1.00000	0.14755	1.15
1981	0.12743	0.13142	0.10362	64,212	130,351	219,417	503,917	991,891	2,117,584	111	1.00000	0.11457	0.89
1982	0.04539	0.16122	0.13175	60,261	195,496	289,524	1,327,556	1,212,632	2,197,452	111	1.00000	0.11510	0.89
1983	0.09660	0.12658	0.11699	57,649	122,280	207,619	596,784	966,043	1,774,743	111	1.00000	0.11612	0.90
1984	0.08884	0.18559	0.20994	35,864	112,429	319,101	403,691	605,791	1,519,951	111	1.00000	0.18478	1.44
1985	0.00000	0.08817	0.17798	0	59,699	291,347	NA	677,128	1,636,972	011	0.77373	0.11737	0.91
1986	0.00998	0.08572	0.16446	3,069	80,569	261,818	307,367	939,950	1,591,939	111	1.00000	0.12167	0.95
1987	0.00000	0.00000	0.18408	0	0	378,940	NA	NA	2,058,587	001	0.56592	0.10417	0.81
1988	0.00000	0.00000	0.21129	0	0	408,057	NA	NA	1,931,300	001	0.56592	0.11957	0.93
1989	0.00000	0.00000	0.11377	0	0	202,327	NA	NA	1,778,409	001	0.56592	0.06438	0.50
1990	0.00000	0.00816	0.20578	0	6,566	291,254	NA	805,038	1,415,369	011	0.77373	0.10378	0.81
1991	0.00000	0.00529	0.13958	0	7,929	194,988	NA	1,499,513	1,396,946	011	0.77373	0.05421	0.42
1992	0.02065	0.00000	0.24419	6,130	0	333,237	296,850	NA	1,364,673	101	0.79219	0.16180	1.26
1993	0.00352	0.00000	0.24709	3,027	0	272,366	858,924	NA	1,102,305	101	0.79219	0.11124	0.86
1994	0.00330	0.00000	0.13738	2,382	0	145,929	721,473	NA	1,062,247	101	0.79219	0.06587	0.51
1995	0.00000	0.00000	0.07801	0	0	80,878	NA	NA	1,036,776	001	0.56592	0.04415	0.34
1996	0.00000	0.00000	0.00000	0	0	0	NA	NA	NA	000	0.00000	0.00000	0.00
1997	0.00000	0.00000	0.04907	0	0	50,844	NA	NA	1,036,198	001	0.56592	0.02777	0.22
1998	0.00115	0.00896	0.00000	1,246	925	0	1,082,015	103,293	NA	110	0.43408	0.00080	0.01
1999	0.02056	0.00000	0.00000	5,511	0	0	267,987	NA	NA	100	0.22627	0.00465	0.04
2000	0.15378	0.00897	0.00000	57,401	3,828	0	373,267	426,797	NA	110	0.43408	0.03322	0.26
2001	0.04906	0.06742	0.00680	41,021	20,355	14,188	836,144	301,900	2,086,008	111	1.00000	0.02344	0.18
2002	0.01924	0.12866	0.00312	36,573	89,012	8,606	1,900,578	691,855	2,758,975	111	1.00000	0.02508	0.19
2003	0.04191	0.10916	0.00000	55,726	96,850	0	1,329,810	887,218	NA	110	0.43408	0.02987	0.23
2004	0.10177	0.08336	0.00816	102,460	34,776	32,335	1,006,737	417,203	3,964,141	111	1.00000	0.03147	0.24
2005	0.19499	0.06536	0.01204	99,926	26,655	16,874	512,480	407,838	1,401,517	111	1.00000	0.06179	0.48

6.4 Next Steps

Step 1. Post-Season Monitoring. The final and simplest application of the HRI metric is for monitoring. The purpose of the HRI metric is to estimate impacts of fisheries as they are actually conducted. Metrics for individual sectors would need to be combined into a metric appropriate for the AABM fishery complex.

Step 2. Develop data standards for inclusion of ER indicator stocks in the calculation of the SPFIs. Multiple variations on the SFPIs were examined for scenarios 1 and 2, which included SPFIs based on nominal vs. AEQ harvest rates and situations that excluded stocks 3 and 9 from the calculation of the SPFIs. The simulation results showed minor differences among these measurements; however it would be helpful to develop standards for the stocks that will be used to calculate SPFIs. Standards may consider the time series of harvest rates (e.g. presence in the base period or recent period or by stratum), estimated CWT recoveries by age, CWT cohort size, nominal or AEQ harvest rates, number of observed tags per fishery stratum, and precision of total estimated tags per fishery stratum.

Step 3. Develop Fishery Policy Scalars. FP scalars need to developed for each fishery, year, stock and age using the strata specific SPFI values. This requires the creation of new Model base exploitation (MDL) files for the affected fisheries. This would normally be done as part of a base period recalibration with the new strata. It also requires an updated ER analysis with the new strata, and a spreadsheet to combine the SPFI estimates using the new strata with the strata specific base period ERs to produce the FP scalars.

Step 4. Develop new AI time series for NBC and WCVI AABM fisheries using the new FP scalars and SPFIs. Another model calibration using the new FP scalars will produce new time series of AIs for the NBC and WCVI AABM troll fishery.

Step 5. Determine if the proportionality constants used to derive catches in Table 1 require revision. The new times series of AIs, from step 2, and corresponding SPFIs can be used to estimate the annual proportionality constants for the Table 1 relationships. The new time series of proportionality constants can be examined with respect to the information used to develop the current Table 1 relationships. Different proportionality constants will be generated for the SPFIs than the ROM indices to relate catch, HRI, and the abundance index.

Step 6. Develop fishery HRI targets that maintain the catch level to AI relationship. If a different proportionality constant is developed, then different HRI targets may be needed to maintain the currently negotiated relationship between allowable catch and abundance.

Step 7. Summarize the evaluation and implications of a policy decision on which option to apply (i.e., maintain the status quo ROM approach or implement new approach based on SPFI).

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Appendix 1. Alternative Method to Estimate Fishery Harvest Rates

By Gary S. Morishima and Ding-Geng Chen

Since the late 1980s, the CTC has employed HRI of various types to try to reflect relative changes in fishery harvest rates over time. Metrics like the Ratio of Means (ROM) and Stratified Proportional fishery index (SPFI) were used because methods to directly estimate fishery harvest rates were not available.

In 2005, Morishima and Chen (2005) devised a method to directly estimate fishery harvest rates using mathematical optimization algorithms to find the set of stock-age-fishery distribution parameters which best accounted for reported catches. The sheer number of computations required to generate harvest rate estimates using those methods was so large that it was impractical to try to apply that approach to the volume of data generated by the Harvest Rate Simulator. Consequently, efforts were initiated to try to find a more computationally efficient method to estimate fishery harvest rates. This Appendix describes a method that simultaneously estimates harvest rates for multiple fisheries during a given time period. In addition to providing estimates of fishery harvest rates, the method generates estimates for the distribution of cohorts among fisheries, providing a means to quantify variability in stock-age distribution patterns among fisheries.

The results presented in the body of this report compare three fishery HRIs that have previously been employed by the CTC, the Simple Average (SA), ROM and SPFI. Although estimates of fishery harvest rates were generated using the methods described in this Appendix, the Small CTC Workgroup did not fully evaluate the performance of this approach. Consideration of this and other alternative ways to estimate fishery HRIs may be undertaken at a later date.

1. Description of Estimation Method

The methods described in this Appendix depend on the same assumption that underlies the algorithms employed to estimate the SPFI metric:

> ***For a given fishery and time period, the harvest rate ($HR_{f,t}$) on all vulnerable fish is the same for all impacted stocks and ages.***

Single Fishery

The ER for a given stock-age-fishery in a given time period can be readily estimated from cohort analysis using CWT data as:

$$ER_{f,s,a,t} = \frac{CWT_{f,s,a,t}}{cwtCOH_{s,a,t}} \qquad \text{(A.1-1)}$$

The ER on the proportion of the vulnerable population that is removed is simply:

$$ER^{PV}_{f,s,a,t} = \frac{ER_{f,s,a,t}}{PV_{f,s,a,t}} \qquad \text{(A.1-2)}$$

The fishery harvest rate is just equation (A.1-2) divided by the proportion of the cohort in the fishery during a given time period $\{D_{f,s,a,t}\}$:

$$HR_{f,s,a,t} = \frac{ER^{PV}_{f,s,a,t}}{D_{f,s,a,t}} \qquad \text{(A.1-3)}$$

Re-arranging,

$$D_{f,s,a,t} = \frac{ER^{PV}_{f,s,a,t}}{HR_{f,s,a,t}} \qquad \text{(A.1-4)}$$

Under the main assumption, the fishery harvest rate is the same for all stocks and ages

$$HR_{f,s,a,t} = HR_{f,t} = \frac{ER^{PV}_{f,s,a,t}}{D_{f,s,a,t}} \quad \forall s,a \qquad \text{(A.1-5)}$$

Consequently, if one distribution parameter $D_{f,s,a,t}$ can be estimated, then all others can be determined. An iterative algorithm is employed to estimate the SPFI metric. This algorithm arbitrarily sets $D_{f,s,a,t}$ =1 for the stock and age with the highest ER on vulnerable fish ($ER^{PV}_{f,s,a,t}$ = $X_{f,t}$ = $maxER_{f,}$). The remaining { $D_{f,s,a,t}$ } can then be determined by simple substitution using equation (4). The algorithm iterates until the relative change in HRs is less than a value specified by the user.

From equations (A.1-4) & (A.1-5), this is equivalent to assuming that $HR_{f,t}$ = $X_{f,t}$:

$$relTD_{f,s,a,t} = \frac{ER^{PV}_{f,s,a,t}}{X_{f,t}} = \frac{ER^{PV}_{f,s,a,t}}{\max ER^{PV}_{f,,t}} \qquad \text{(A.1-6)}$$

The $\{rel\,D_{f,s,a,t}\}$ resulting from this procedure represents the distribution of cohorts relative to the cohort associated with $X_{f,t}$.

The $HR_{f,t}$ resulting from this method will not represent the true fishery harvest rate, but a relative fishery harvest rate. Relative changes in fishery harvest rates can be computed over several years for a single fishery-time period stratum.

Multiple Fisheries

Now let's consider multiple fisheries (e.g., F) and assume that all the fish from a given stock and age cohort are distributed among them.

If we employ the procedure described above for each of these fisheries, we will obtain F sets of distribution parameters $\{D_{1,s,a,t}\} \ldots \{D_{F,s,a,t}\}$. For a given stock, age and time period,

$$\sum_{f=1}^{F} D_{f,s,a,t} = 1 \qquad \text{(A.1-7)}$$

Define a set of fishery-specific scalar values $\{Z_{f,t}\}$ such that for all stocks and ages

$$\sum_{f=1}^{F} Z_{f,t} * relD_{f,s,a,t} = 1 \qquad \text{(A.1-8)}$$

The individual elements of the summation in equation (A.1-8) represent the true stock distribution parameters $\{D_{f,s,a,t}\}$:

$$D_{f,s,a,t} = Z_{f,t} * relD_{f,s,a,t} \qquad \text{(A.1-9)}$$

The true fishery harvest rates (THR) can now be estimated as:

$$\left\{ THR_{f,t} = \frac{X_{f,t}}{Z_{f,t}} \right\} \qquad \text{(A.1-10)}$$

The challenge is to find the set $\{Z_{f,t}\}$ which satisfies equation (A.1-8).

Let's return to the basic assumption. The catch is simply the abundance of vulnerable fish multiplied by the true harvest rate:

$$C_{f,t} = \sum_{s}\sum_{a} COH_{s,a,t} * PV_{f,s,a,t} * THR_{f,t} \qquad \text{(A.1-11)}$$

This estimated catch can be compared to the observed catches ($OC_{f,t}$).

We can estimate { $Z_{f,t}$ } using a simple quadric programming model with linear constraints. Find the {$Z_{f,t}$} which minimizes

$$\sum_{f=1}^{F}(C_{f,t} - OC_{f,t})^2 \qquad \text{(A.1-12)}$$

Subject to the constraints:

$$\left\{\sum_{f=1}^{F} Z_{f,t} * relD_{f,t,s,a} = 1\right\} \text{ for all stocks and ages.} \qquad \text{(A.1-13)}$$

The annual fishery harvest rate is computed as the gauntlet statistic described in Chapter 5 (titled "Evaluation of Harvest Rate Indices").

This method is much more computationally efficient than that developed by Morishima and Chen in 2005. Only one parameter needs to be estimated per fishery instead of many stock-age-fishery distribution parameters. Harvest rates can be estimated using Excel solver.

Closed Fishery

The methods described above will work if there are catches and CWT recoveries in all fisheries for a given time period. However, when a fishery is closed the method will not work; there will be no CWT recoveries in that fishery and hence no ERs would be available to estimate distribution parameters. In this case, we know that equation (A.1-7) will not hold for the stock-age groups that are actually distributed to the area where the closed fishery operates. However, the Z's for the open fisheries can still be estimated under certain conditions. From a time series of CWT recoveries, we can identify stock-age groups that are rarely encountered in the time period in which the fishery is closed by using the following procedure:

Include only the subset of stock-age groups that are rarely encountered in the closed fishery-time period to estimate the Zs for the open fisheries. This approach essentially assumes that the D's for those groups = 0, i.e., equation (A.1-7) for the open fisheries =1.

Estimation when equation (A.1-7) does not hold.

The above methods correctly estimate the fishery harvest rates if there is no sampling error in the catch or cohort reconstructions from CWT recoveries. However, both fishing and CWT recoveries are subject to sampling process error. It is still possible to estimate fishery harvest rates reversing the formulation presented in equations (A.1-12) and (A.1-13). That is, we can estimate { $Z_{f,t}$ } using a simple quadric programming model with linear constraints. Find the { $Z_{f,t}$ } which minimizes

$$\sum_{s}\sum_{a}(1-\sum_{f=1}^{F} D_{f,s,a,t})^2 \qquad \text{(A.1-12a)}$$

Subject to the constraints:

$$C_{f,t} = OC_{f,t} \quad \text{for all open fisheries.} \qquad \text{(A.1-13a)}$$

2. Computational Approach

Code was developed using the statistical package "R" to generate harvest rate estimates from the large number of datasets produced by the Harvest Rate Simulator. For computational efficiency, the estimation problem was reformulated so it could be solved using matrix algebra.

From equations (A.1-4) and (A.1-7),

$$\sum_{f=1}^{F} D_{f,s,a,t} = \sum_{f=1}^{F} \frac{ER^{PV}_{f,s,a,t}}{HR_{F,t}} = 1 \qquad \text{(A.1-14)}$$

For a given time period, t, we can construct a matrix *matER*, with s x a (stock * age) rows and F columns:

$$matER = \left(ER^{PV}_{1,s,a,t},\ldots,ER^{PV}_{F,s,a,t}\right)_{s \times a} \qquad \text{(A.1-15)}$$

Now, define a vector *vecHR*, consisting of F elements:

$$vecHR = \left(\frac{1}{HR_{1,t}},\ldots,\frac{1}{HR_{F,t}}\right)_F \qquad \text{(A.1-16)}$$

And a vector vec1, consisting of s x a (stock * age) elements = 1:

$$vec1 = \left(1,\ldots,1\right)_{sxa} \qquad \text{(A.1-17)}$$

Equation (A.1-14) can now be represented in matrix form as:

$$matER \times vecHR = vec1 \qquad \text{(A.1-18)}$$

And equation (A.1-18) can be solved by Least Squares Estimation (LSE) to minimize $\sum_{s,a}(1-\sum_{f} D_{f,s,a,t})^2$, the sum of the deviations of the elements of vec1 from 1.

In matrix form, the estimation problem can be expressed as:

$$vecHR = \left(matER^T \times matER\right)^{-1} \times matER^T \times vec1 \qquad \text{(A.1-19)}$$

The fishery harvest rates can be obtained by the inverse of the elements of *vecHR*. The formulation of the estimation problem in this way is computationally efficient because only one parameter per fishery is estimated and there is no need to employ optimal search strategies. The estimation procedure was tested using several simulated datasets and found to accurately estimate true values.

3. Special Case: Complications Resulting from the Structure of the Harvest Rate Simulator.

The Harvest Rate Simulator was structured to generate data to evaluate the impacts of changes in fishing patterns on alternative fishery HRIs. In the scenarios used for evaluation, stock-age compositions are identical for fisheries 3 and 4 for all time periods, but the proportion of the total annual allowable catch taken in individual time periods can differ for some years. This structure can result in datasets where $HR_{3,t} = HR_{4,t}$. When this condition occurs, $D_{3,s,a,t} = D_{4,s,a,t}$ and $ER_{3,s,a,t} = ER_{4,s,a,t}$. Since ER=HR*D, *matER* is singular or degenerate. Because there are confounding results when stock compositions and allowable catches for fisheries 3 & 4 are identical or nearly so, estimates of fishery harvest rates produced under these conditions can be prone to substantial error.

It is highly unlikely that such circumstances would arise in the real world. However, the following procedure was developed as a work around to try to find a way to generate estimates of fishery harvest rates under the scenarios produced by the Harvest Rate Simulator. Because the method depends on prior knowledge of the scenarios produced by the Harvest Rate Simulator, it could not be generally applied.

Generate an alternative form of equation (A.1-14) assuming that $HR_{3,t} = HR_{4,t}$:

$$\begin{aligned}\sum_{f=1}^{F} D_{f,s,a,t} &= \sum_{f=1}^{F} \frac{ER_{f,s,a,t}^{PV}}{HR_{f,t}} = \frac{ER_{1,s,a,t}^{PV}}{HR_{1,t}} + \frac{ER_{2,s,a,t}^{PV}}{HR_{2,t}} + \frac{ER_{3,s,a,t}^{PV}}{HR_{3,t}} + \frac{ER_{4,s,a,t}^{PV}}{HR_{3,t}} \\ &= \frac{ER_{1,s,a,t}^{PV}}{HR_{1,t}} + \frac{ER_{2,s,a,t}^{PV}}{HR_{2,t}} + \frac{ER_{3,s,a,t}^{PV} + ER_{4,s,a,t}^{PV}}{HR_{3,t}} = 1\end{aligned} \qquad \text{(A.1-20)}$$

Define

$matER = \left[ER_{1,s,a,t}^{PV}, ER_{2,s,a,t}^{PV}, ER_{3,s,a,t}^{PV} + ER_{4,s,a,t}^{PV}\right]_{s \times a}$ (all ER data organized into matrix with *s* times *a* rows, 3 columns for fisheries, for each time period

$$vecHR = \left(\frac{1}{HR_{1,t}}, \frac{1}{HR_{2,t}}, \frac{1}{HR_{3,t}} \right)$$ (a vector with 3 elements for 1/HRs)

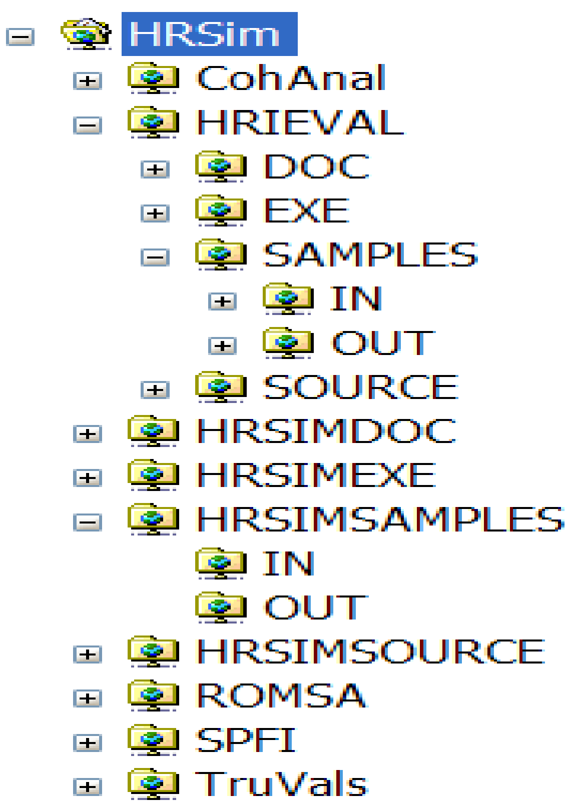
and $vec1$ is a vector with *s* times *a* elements = 1.

Appendix 2. Program files and input files used for this analysis.

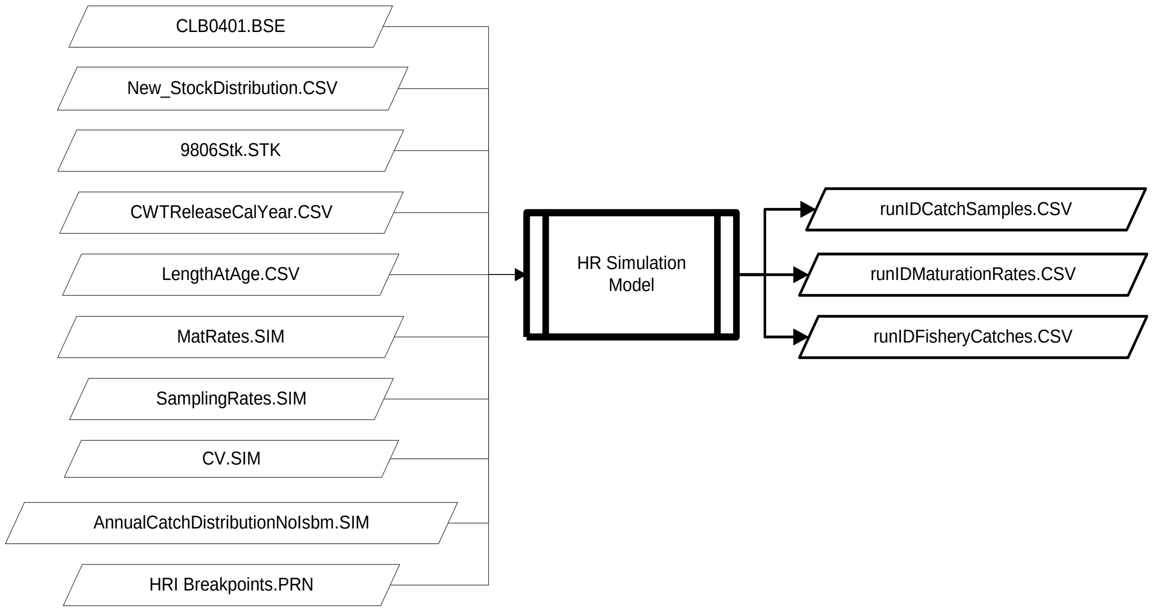
The programs reside on the PSC ftp site at ftp://ftp.psc.org/Pub/tcchinook/HRSIM with a directory structure as depicted in Appendix Figure 2 - 1. Several programs were used in completing this task including,

- HRSim.EXE – the fishery harvest model is described in Chapter 2 (Appendix Figure 2 - 2)
- EREstimland.EXE – the cohort analysis estimation program described in Chapter 3 (Appendix Figure 2 - 3),
- ROMSA – programs that produced the HRI estimates using the Ratio of Means (ROM) and Simple Average (SA) methods described in Chapter 4 (Appendix Figure 2 - 4)
- RunRecA.EXE – the program that calculates the true values of the HRI from the output from the HRSim model program (Appendix Figure 2 - 5)
- SPFI programs – a series of programs that produces the Stratified Proportional Fishery Index method for estimating the HRI described in Chapter 4 (Appendix Figure 2 - 6)

Appendix Figure 2 - 2 to Appendix Figure 2 - 6 provide flowcharts for each of these programs and describes the input and output files used.



Appendix Figure 2 - 1. Directory HRSIM on the CTC ftp site maintained by the PSC (ftp://ftp.psc.org/Pub/tcchinook/HRSim).

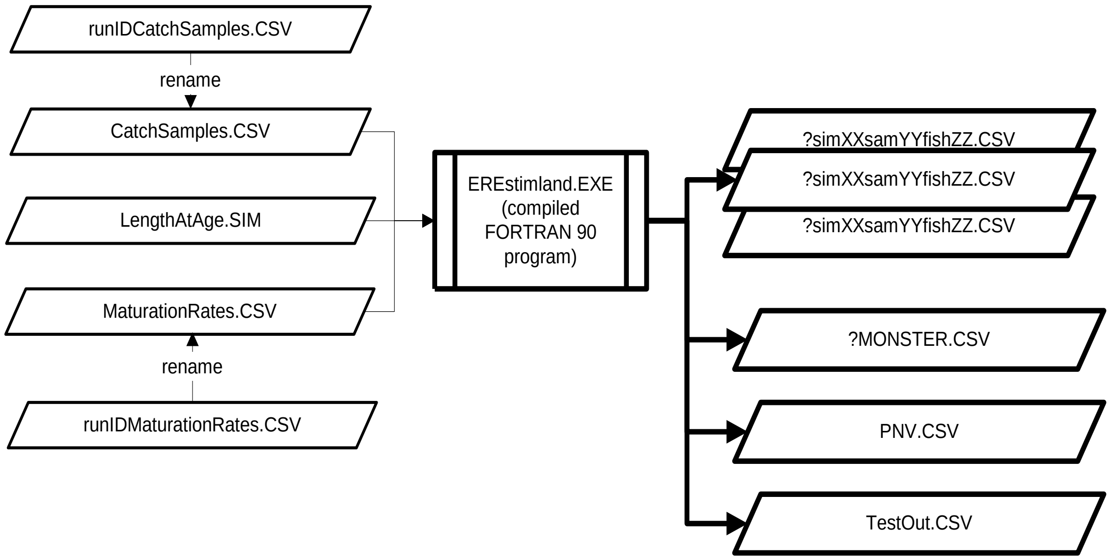


Appendix Figure 2 - 2. Input and Output files for HRI Simulation Model program HRSim.EXE.

HRSim.EXE is a compiled executable produced by a program written in Visual Basic
.

INPUT Files: Described in Appendix 5.

OUTPUT Files: Described in Appendix 5

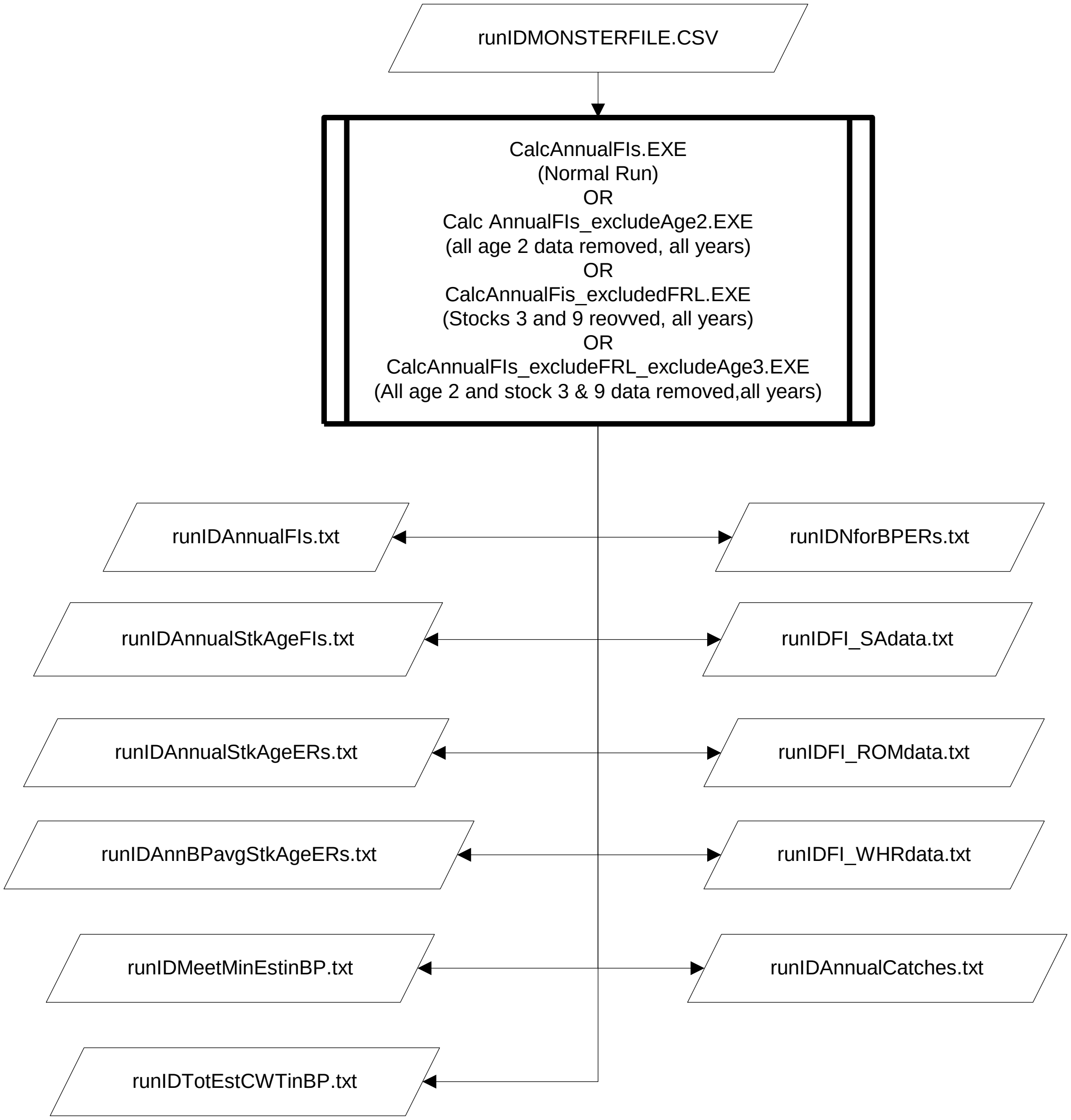


Appendix Figure 2 - 3. Input and output files for Program EREstimland.EXE to generate cohort analysis from CWT recoveries generated by the HRI Simulation Model

EREstimland.EXE is a compiled executable produced by a program written in FORTRAN 90.

INPUT Files: Described in Appendix 5.

OUTPUT Files: Described in Appendix 6



Appendix Figure 2 - 4. Input and output files for generation of HRIs for simple average (SA), ratio of means (ROM) and weighted harvest rate (WHR) annual HRI metrics.

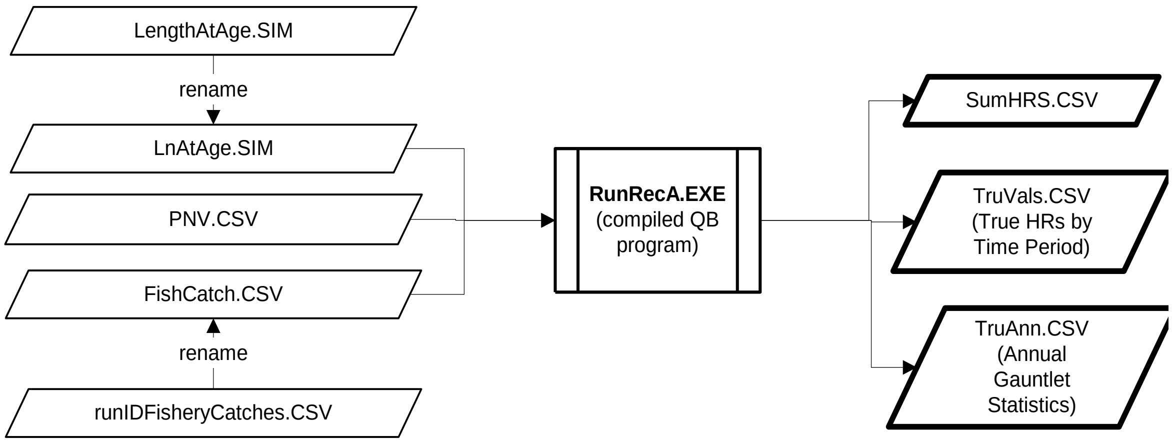
*.EXE are compiled executables of AWK programs developed to generate estimates of annual SA, ROM, and WHR HRI metrics for all preterminal ocean fisheries.

CalcAnnualFIs.exe	Normal Run
CalcAnnualFIs_excludeAge2.exe	All age 2 data removed, all years
CalcAnnualFIs_excludeFRL.exe	Stock 3 and 9 removed, all years
CalcAnnualFIs__excludeFRL_excludeAge2.exe	All age 2 data and stock 3 and 9 data removed, all years

INPUT Files: runIDMONSTERFILE.CSV generated by erestimland.EXE.
OUTPUT Files:

runIDAnnualFIs.txt	Complete and 3 incomplete versions the annual HRIs: SA, ROM & WHR
runIDAnnualStkAgeFIs.txt	Stock-age HRIs for annual time period
runIDAnnualStkAgeERs.txt	Stock-age ERs for annual time period, same format as above
runIDAnnBPavgStkAgeERs.txt	Mean stock-age ERs during the base period
runIDMeetMinEstinBP.txt	Y or N indicates whether stk-age combo meets BP criterion of > 70 total CWTs
runIDTotEstCWTinBP.txt	Total estimated CWTs during the two base period years
runIDNforBPERs.txt	Sample size for base period average data (max =2)
runIDFI_SAdata.txt	Data components used in calculation of the SA HRI
runIDFI_ROMdata.txt	Data components used in calculation of the ROM HRI
runIDFI_WHRdata.txt	Data components used in calculation of the WHR HRI
runIDAnnualCatches.txt	Stock-age CWT catch for calendar year, same format as above

All output is in space separated ASCII text format by iteration, sample, year, fishery with some by stock & age as well. Only data for 1982, 1983, 1985, 1986, 1991 and 1992 are output.



Appendix Figure 2 - 5. Input and output files program RunRecA.EXE for generation of true values for comparison of HRI metrics.

RunRecA.EXE is a compiled executable of a Quick Basic 4.0 program. **NOTE:** When running the program, select option 1. Option 2 generates a variety of statistics for debugging of HRI Simulation Model.

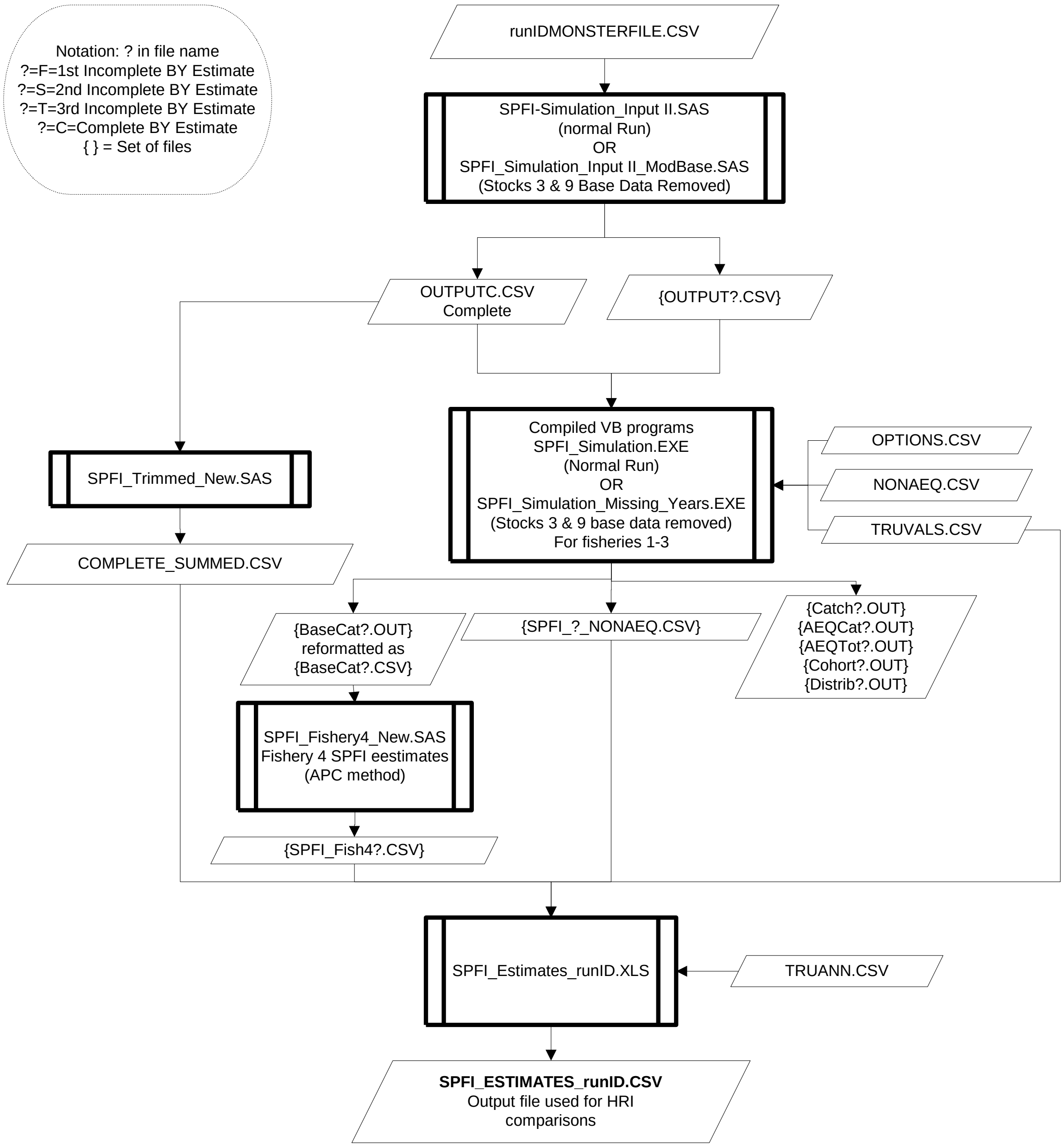
INPUT Files: Described in Appendix 5. In Quick Basic, file names are limited to 8 characters plus a 3 character extension. Consequently, the files LengthAtAge.SIM and runIDFisheryCatches.CSV must be renamed.

OUTPUT Files:

SumHRS.CSV: True Catches and HRs by fishery and time period

TruVals.CSV: Total Abundance, PV Population, Catches, and Harvest Rates by fishery and time period

TruAnn.CSV: Total Abundance and PV at start of Period 1, total catch for year, True HR based on period 1 abundance, and gauntlet statistic by fishery and year .



Appendix Figure 2 - 6. Input and Output Files for calculation of SPFI

SPFI_Simulation_Input II_ModBase.SAS: SAS program to extract data sets from ?MONSTERFILE.CSV, excluding base data for Stocks 3 and 9 (untagged during base period).

INPUT Files: runIDMONSTERFILE.CSV produced by EREstimland.EXE described in Appendix 6.
OUTPUT Files: {OUTPUT?.CSV}
? = F = 1st incomplete brood year estimates of ERs
= S = 2nd incomplete brood year estimates of ERs
= T = 3rd incpmplete brood year estimate of ERs

= C = Complete brood year estimate of ERs

SPFI_Simulation.EXE: Compiled Visual Basic 6 Program to generate data for fisheries 1-3 for a Normal Run

SPFI_Simulation_Missing_Years.EXE: Compiled Visual Basic 6 Program to generate data for fisheries 1-3, excluding base data for stocks 3 and 9.

INPUT Files:

OUTPUT?.CSV , OPTIONS.CSV, and NONAEQ.CSV are described in Appendix 5.
TRUVALS.CSV is generated by RunRecA.EXE

OUTPUT Files:

Catch?.OUT: CWT catch estimates (space delimited ASCII format)
aeqCat?.OUT: CWT Catch estimates in adult equivalents (space delimited ASCII format)
aeqTot?.OUT: CWT Total mortality estimates in adult equivalents (space delimited ASCII format)
Cohort?.OUT: Estimated cohort sizes (space delimited ASCII format)
Basecat?.OUT: CWTHR, Catch, AEQCatch, Abundance (space delimited ASCII format)
Distrib?.OUT: proportion of total catch by time period (space delimited ASCII format)
SPFI_?_NONAEQ.CSV. SPFI estimates for Fisheries 1-3 (comma separated values)

SPFI_Fishery4.NEW.SAS: SAS program for fishery 4, using the APC method.

INPUT Files:

Basecat?.CSV: Renamed file generated by SPFI_Simulation?.EXE .

OUTPUT Files:

SPFI_FISH4?.CSV: SPFI estimates for Fishery 4.

SPFI_TRIMMED_NEW.SAS: SAS program

INPUT Files:

OUTPUTC.CSV: Generated by SPFI_Simulation_Input II?.SAS

OUTPUT Files:

COMPLETE_SUMMED.CSV: Number of parameters to estimate (Stock-age-strate combinations by iteration, sample, fishery, and year used for Aikeke Information Criterion.

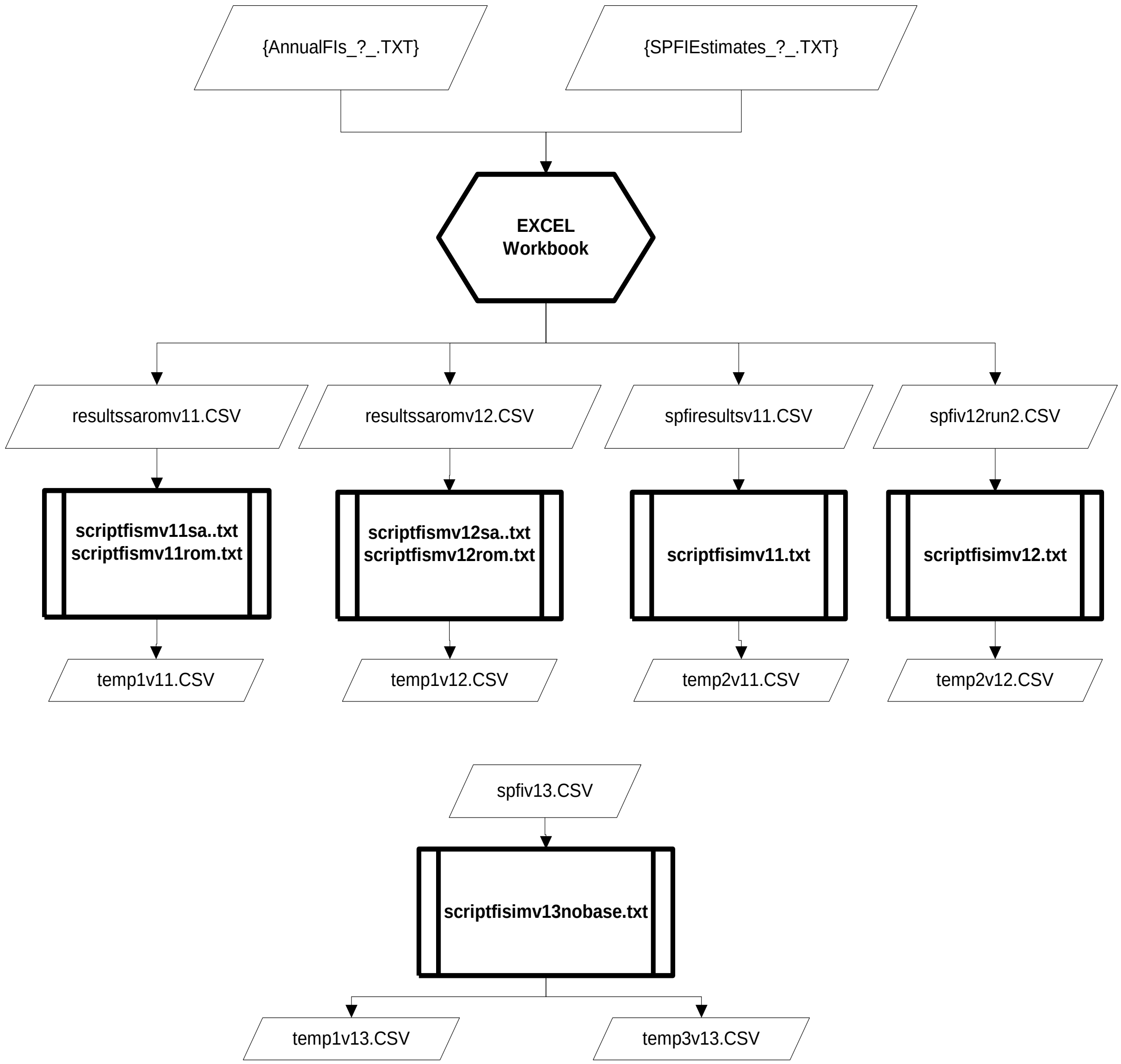
SPFI_ESTIMATES_ runID.XLS: Excel workbook to generate file for comparison of HRI metrics

INPUT Files:

{SPFI_?_NONAEQ.CSV}: Produced by SPFI_Simulation?.EXE
{SPFI_FISH4?.CSV}: Produced by SPFI_Fishery4_NEW.SAS
TRUVALS.CSV and TRUANN.CSV produced by RunRecA.EXE
COMPLETE_SUMMED.CSV produced by SPFI_TRMMED.NEW.SAS

OUTPUT File:

SPFI_Estimates_runID.CSV: SPFI estimates, True HRs, and number of parameters to produce output file for HRI comparisons



Appendix Figure 2 - 7. Input and output files for generation of tables and graphs comparing alternative HRI metrics.

*.TXT scripts for the R statistical package to produce complete brood year comparisons.

EXCEL	Refers to use of MS EXCEL software
Scriptfisimv11sa,TXT	R Script for Simple Average Run 11
Scriptfisimv12sa,TXT	R Script for Simple Average Run 12
Scriptfisimv11rom,TXT	R Script for Ratio of Means Run 11
Scriptfisimv12rom,TXT	R Script for Ratio of Means Run 12
Scriptfisimv11.TXT	R Script for SPFI Run 11
Scriptfisimv12.TXT	R Script for SPFI Run 12
Scriptfisimsv13nobase.txt	R Script for SPFI with data for stocks 3 and 9 removed and incomplete broods

INPUT Files:

AnnualFIs_Scen1_Sep2108.txt	Reformatted and renamed output file for scenario 1 converted from ASCII text to CSV files, originally generated by AWK programs (fig App2-6)
AnnualFIs_Scen2_Sep2108.txt	Reformatted and renamed output file for scenario 2 converted from ASCII text to CSV files, originally generated by AWK programs (fig App2-6)
SPFIEstimates4142008.csv	Renamed CSV file generated by SAS programs (fig app2-5)
SPFIEstimates4152008.csv	Renamed CSV file generated by SAS programs (fig app2-5)
spfiv13.csv	Renamed CSV file generated by SAS programs (fig app2-5)

OUTPUT Files:

resultssaromv11.CSV	Output file for simulation v11 generated using EXCEL containing annual HRI estimates for simple average and ratio of means HRI metrics for complete broods
resultssaromv12.CSV	Output file for simulation v12 generated using EXCEL containing a nnual HRI estimates for simple average and ratio of means HRI metrics for complete broods
spfiresultsv11.CSV	Output file for simulation v11 generated using EXCEL containing annual HRI estimates for SPFI for complete broods
spfiv12run2.CSV	Output file for simulation v12 generated using EXCEL containing annual HRI estimates for SPFI for complete broods
temp1?.CSV	Output file containing estimates of relative error for annual SA & ROM HRI estimates using complete brood year data.
temp3?.CSV	Output file containing estimates of relative error, RMSE, Likelihood, and AIC for annual SPFI estimates using complete brood year data.
temp1?.CSV,temp3?.CSV	Output files containing estimates Output file containing estimates of relative error, RMSE, Likelihood, and AIC for annual SPFI estimates using complete brood year data with data for stocks 3 and 9 removed.

Pseudocode

1) Take output from Gayle Brown (files Annula FI's Scen 1 and Annual FI scen 2) and John Carlile (SPFI estimates ***.csv) and process in Excel
with Gauntlet Stat as the real measure.
2) Input the ***.csv files into R.
3) Process it by Fishery, Scenario (iteration) and Simulation (SampID) to assess Relative Error in R.
4) Plot graphs in R on Relative error versus Fishery and Year.
5) Compute summary distributions in Step 4 above and output a table with values.
6) Compute RMSE using the data and summarize by fishery and year.
7) Compute the Likelihoods, and AIC by Fishery and Year.
8) Output all these results into another output-file.
9) Run each FI separately, first SA, second ROM and third SPFI, and write ouput files for each run and index separately.

Note: Each R script has to be run separately for each Index and Run. In addition, note that the output files need to be renamed each time after running the programs inorder to prevent over-writing of files.

Appendix 3. Description of harvest rate simulation model.

Model Description

The performance of alternative HRI metrics can best be evaluated by comparing estimated values with true values. A model, written in Visual Basic Express 2008 (VB.Net), was developed to generate catch and CWT recovery data for evaluation of alternative HRI metrics. The model simulates ocean and terminal fishing and catch sampling of hatchery and wild Chinook stocks. Statistics on the true catch and incidental mortalities by fishery by stock and age and escapement by stock and age are produced. Model processes for a Chinook stock include migration, growth, maturation, and natural mortality (Appendix Figure 3- 1). Model processes for a fishery include catch limits (quotas) or harvest rate controls, incidental mortality and drop-off mortality. Sampling processes include simulation of CWT recovery programs for catch and escapement.

A model year begins October 1 and is divided into three time periods of unequal length. The time periods are October through April, May and June, and July through September. A mixture of sixteen spring and fall type stocks is represented in the model. The model currently simulates four preterminal, AABM fisheries and one terminal fishery. Two of the AABM fisheries (fishery numbers 3 and 4) were modeled with identical initial stock compositions and annual harvest levels, but with different distribution of catch among time periods to permit evaluation of the effects of changes in fishing patterns on HRI performance; specifically, fishery 4 was closed during one of the time periods for some years.

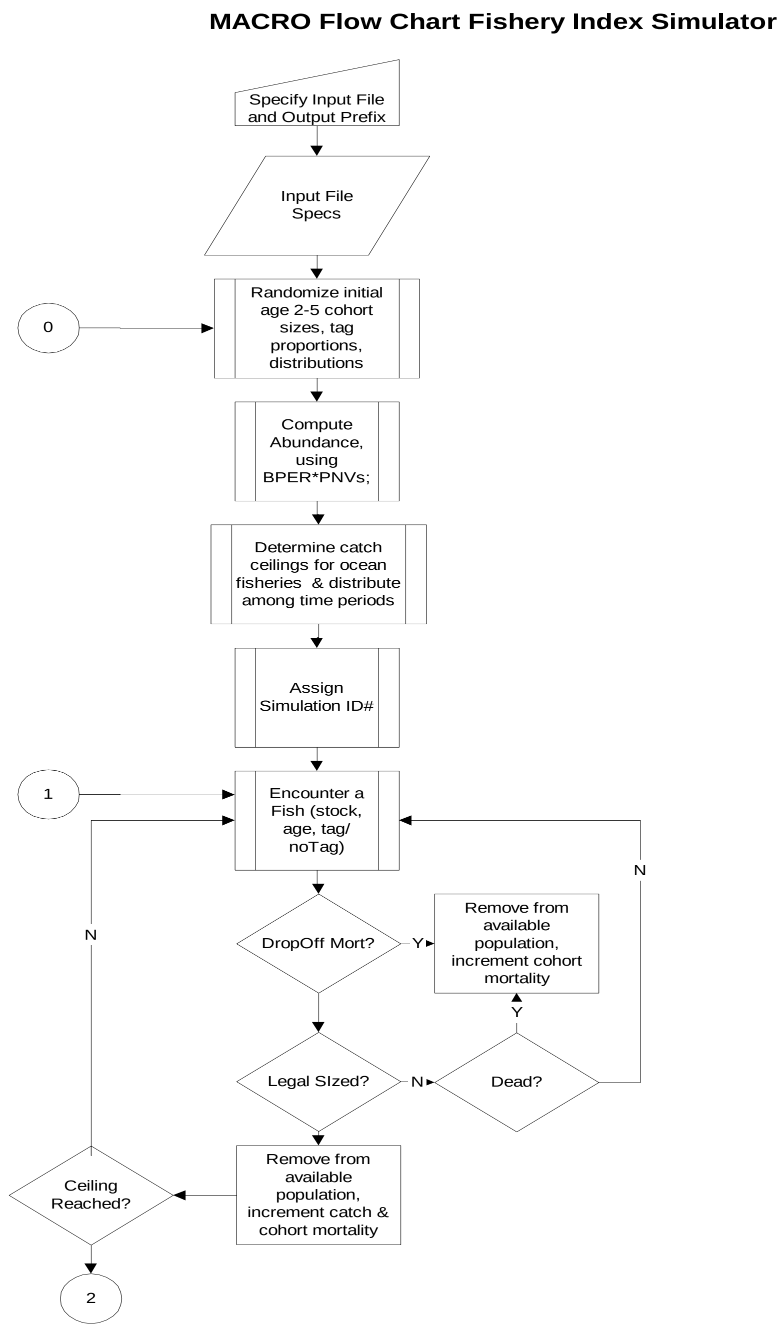
Monte Carlo methods were employed to simulate the effects of stochastic variability on the following processes:

- Abundance of Age 2 cohort sizes.
- The proportion of age 2 production that is tagged with CWTs.
- Distribution of stocks among preterminal fisheries.
- Legal-Sublegal size of fish encountered.
- Drop-off mortality.
- Maturation Rates.
- CWT sampling.

Stochasticity was simulated using random numbers generated using the Marsenne Twister algorithm MT19937 from Matsumoto and Nishimura (1998). This algorithm, which passes numerous tests for statistical randomness, was employed because it has several advantages compared to the random number generator function built into Visual Basic:

1. Suitable periodicity (repetition of random number sequences) for the simulation. The Marsenne Twister has a period of $2^{19937} - 1$ (2^{19937} is approximately $4.315425 \times 10^{6001}$).

2. The high order of dimensional equidistribution implies that there is negligible serial correlation between successive values in the output sequence.



Appendix Figure 3- 1. Flow Chart for Harvest rate index Simulation Model

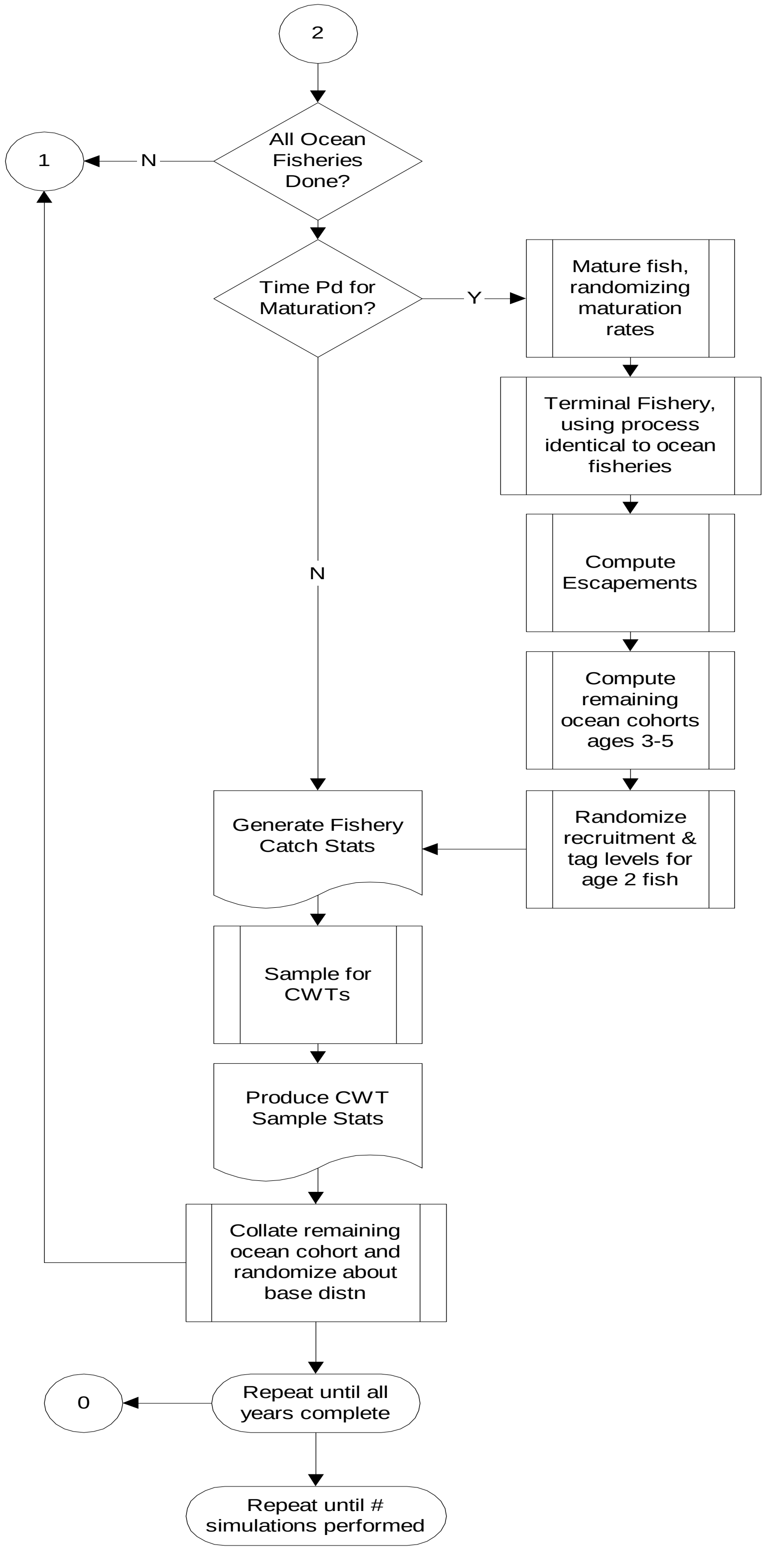
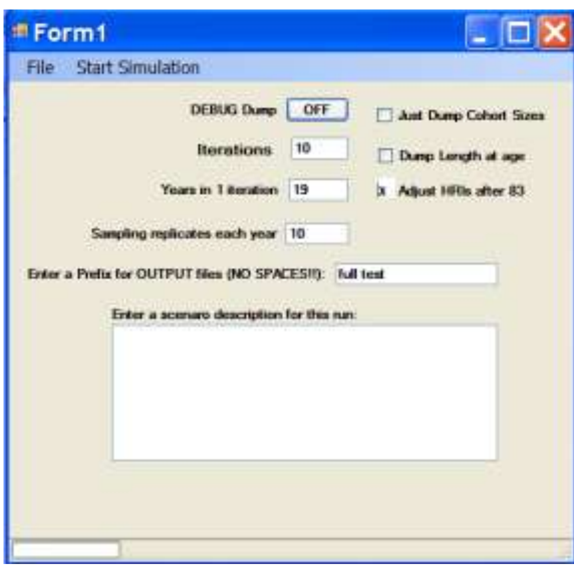
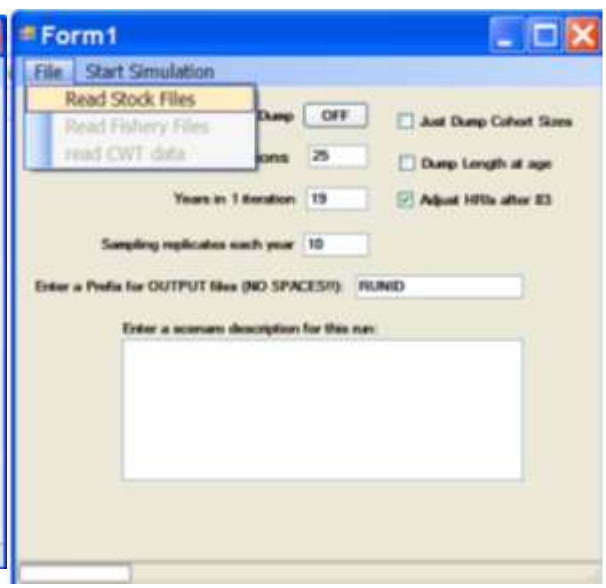


Figure Appendix 3-1 continued. Flow Chart for Harvest rate index Simulation Model

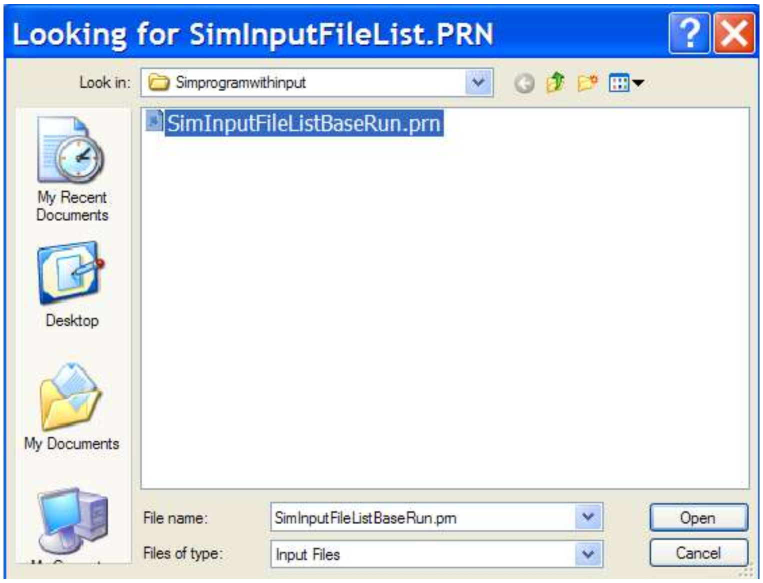
Parameters governing the processes affected by various scenarios are provided via a set of input data files and parameters provided via the input screen. Aspects such as the number of replicates, length of each simulation run, break points for abundance indices and harvest rate scalars, distribution of individual stocks among the AABM fisheries, the tagging schedule and proportion of age 2 production tagged by stock, and CWT sampling rates can be readily altered. The number of replicates employed for the scenarios can be controlled to evaluate random variability in stock and fishery behavior. For each scenario replicate, catches can be sampled repeatedly to obtain information on the impact of sampling error on CWT recoveries.

When the model is run, the screen depicted below to the left appears. The DEBUG Dump check box allows the cohort sizes and lengths at age to be dumped to a file for debugging. The number of times a scenario is to be repeated, length of a simulation run, and the number of CWT samples to be modeled are specified in dialogue boxes identified by "Iterations", "Years in 1 iteration", and "Sampling replicates for each year", respectively. The user enters a runID in the dialogue box "Enter a Prefix for OUTPUT files (NO SPACES!!)" to identify output files generated by the model for a particular run. A description of the run can be entered in the dialogue box as a reminder of the scenario being modeled. The checkbox "Adjust HRIs after 83" applies hard-coded scalar values (0.7 for fisheries 1&2, 0.3 for fisheries 3&4) to the HRIs starting in 1984 to run the two scenarios that were used to generate data with the same model parameter input values.

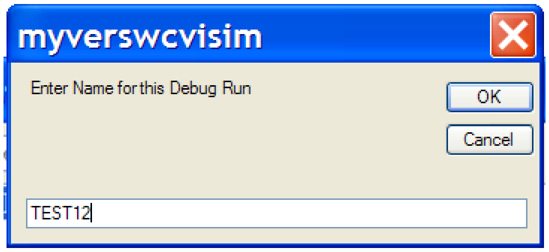




Once these options are chosen, the menu items at the top of the display screen should be selected as shown in the screen to the right above. The "File" menu displays three items, as shown, but only the "Read Stock Files" item is functional. Selecting this item will open a window asking the user to specify the name of the file containing the list of input files (see "Input File Description"). This file can have any name, but must end with *.PRN*. The screen below shows an example where the input filename is SimInputFileList.PRN. Once that file is specified, select the "Start Simulation" button to start the model.



Finally the model program will request a name for the debug dump file, and you can use any name. The program will assign it a .CSV file type.



Input file descriptions

The input files (ASCII text) containing Model parameters are specified through the use of a CSV delimited ASCII "*?.PRN*" text file. The only restriction on the file name is that it should end in "*.PRN*". The file "*SimInputFileBase.PRN*" was used for the Model runs reported herein. The format of the file is described in Appendix Table 3- 1 (names of files employed for the simulation runs described in this report are contained in parentheses).

Appendix Table 3- 1. Format of file that provides Model program with list of input files.

Line	Content	Comment/Description
1	Title to identify file set	
2	*?.BSE (CLB0401.BSE)*	File used by the PSC Chinook Model. HR Model extracts incidental mortality rates and stock run type (spring/fall) flags
3	*?.CSV (New_StockDistribution.CSV)*	Contains stock-age distribution of cohorts among the four preterminal fisheries by time period

Line	Content	Comment/Description
4	*?.STK (9806STK.STK)*	File used by the 2008 PSC Chinook Model calibration. HR Model extracts stock three-letter acronyms (TLA), initial cohort abundances, and Stock-Age-Fishery ERs for vulnerable cohorts in preterminal and terminal fisheries
5	*?.CSV (CWTReleaseCalYear.CSV)*	Contains CWT release information for individual stocks by year
6	*?. SIM (LengthAtAge.SIM)*	Average lengths and standard deviations by stock by age for time periods as estimated by Morishima and Chen under Letter of Agreement (LOA Model Reformulation Project). The Harvest Rate Model uses only data from time periods 2, 3 and 4.
7	*?.SIM (MATRATES.SIM)*	Average maturation rates for individual stocks and Standard Deviations about those rates estimated from the PSC Chinook Model input file MATFRL.DAT
8	*?.SIM CWT (SamplingRates.SIM).*	Base CWT sampling rates for the five fisheries in the model and for stock-specific escapement
9	*?.SIM (CV.SIM)*	Coefficients of variation for stochastic processes
10	*?.SIM (ANNUALCATCHDISTRIBUTIONnoisbm.SIM)*	Proportion of annual catch by time period for the four preterminal fisheries
11	*?.PRN (HRI Breakpoints.PRN)*	For each of the four preterminal fisheries, three HRI levels are specified. This file contains the two abundance levels that trigger these HRIs for each preterminal fishery.

The .BSE and .STK files provide information on fisheries and stocks and are used by the PSC Chinook model. The Harvest Rate model extracts subsets of data from these files as seed values, but there was no intention to try to mimic the exact same fisheries or stocks in the PSC Chinook model (Appendix Table 3- 2). Instead fisheries data were chosen in such a manner that they would represent a range of ocean fisheries from North to South as well as include a representative terminal fishery. In like manner, stock data were chosen so that the simulated stocks would represent a range of life histories, run types and geographic spawning distributions.

Appendix Table 3- 2. The correspondence between the fisheries and stocks in the Harvest Rate and the PSC Chinook Models.

Harvest Rate Simulator	PSC Chinook Model Fisheries and Stocks Mimicked
Fishery 1	SEAK T
Fishery 2	NBC T
Fishery 3	WCVI T
Fishery 4	WCVI T (2) Fishery 4 is intended to be identical to fishery 3 in all respects except the fishing pattern. The Harvest Rate Model scenarios were structured to evaluate the effect of eliminating fishing during one time period on HRI metrics computed for Fisheries 3 and 4.
Fishery 5	Terminal Net
Stock 1	AKS
Stock 2	FRE
Stock 3	FRL
Stock 4	RBH
Stock 5	RBT
Stock 6	GSQ
Stock 7	NKF
Stock 8	PSF
Stock 9	SKG
Stock 10	WCH
Stock 11	URB
Stock 12	SPR
Stock 13	CWF
Stock 14	WSH
Stock 15	ORC
Stock 16	WCN

Stock acronyms are read from the .STK file, as are 'starting' cohort sizes. The initial cohort sizes for all ages (2-5) are used to seed the simulation model at the start of each iteration. Age 2 starting cohort sizes are also used as incoming age 2 cohorts at the start of each year in each iteration. All cohorts are randomized by the simulation model before use. ERs on the vulnerable population by age and fishery are also input from this file. Since the ocean fisheries in the simulation model are modeled as quota fisheries, these input ERs are used in the calculation of the Abundance Index each year, but are not used in the fishing model process.

Formats for the different types of input files (except for the files identified in lines 2 and 4 since the file types are identical to those employed by the PSC Chinook Model) are described below in Appendix Table 3- 3 to Appendix Table 3- 10. For specific parameter values used in the Harvest Rate Simulator, each of the files should be examined using a text editor.

Appendix Table 3- 3. Stock distribution CSV file specified in Line 3 in Appendix Table 3- 1 First line in file contains column headers. Format for lines 2+ is described below. The sum of items 4-7 MUST equal 1.0.

Item (Col#)	**Description**
1	Three Letter Acronym for Stock
2	Time Step (T1, T2, T3)
3	Age
4	Proportion of cohort distributed to Preterminal Fishery 1
5	Proportion of cohort distributed to Preterminal Fishery 2
6	Proportion of cohort distributed to Preterminal Fishery 3
7	Proportion of cohort distributed to Preterminal Fishery 4

Appendix Table 3- 4. Format for lines 3+ of CWT release CSV file specified in Line 5 in Appendix Table 3- 1. First two lines contain header information.

Item (Col#)	**Description**
1	Three Letter Acronym for Stock
2	Minimum number of age 2 fish containing CWTs if stock is tagged
3	Average tagging rate (proportion of age 2 cohort that is tagged when CWTs are applied)
4	Standard deviation about average tagging rate
5	No longer used in program. Relic which indicates whether a fish was tagged in any year
6-24	Yearly flags to indicate if age the 2 cohort is to be tagged (Y/N for 1978, 0=no, 1=yes for 1979-1997).

Appendix Table 3- 5. Formats for lines 3+ in each set (CSV delimited) of the Length-at-age file specified in Line 6 in Appendix Table 3- 1. There are sixteen sets of data, one for each stock. The first line of each set contains descriptive information and stock acronym. Second line contains header information.

Item (Col#)	**Description**
1	Ocean age
2	Annual time period
3	Mean average length
4	Standard deviation about average length

Appendix Table 3- 6. Format for lines 3+ (space delimited) of maturation rate file specified in line 7 in Appendix Table 3- 1. First two lines in the file contain header information.The maturation rate for age 5 is fixed at 1.00.

Item Col#)	Description
1	Stock acronym
2	Age 2 average maturation rate from CTC ER analysis
3	Standard deviation about average age 2 maturation rate as estimated from CTC ER analysis (This is a relic parameter no longer used; CVs for maturation rates are hard coded in the program at 0.1).
4	Age 3 average maturation rate from CTC ER analysis. (This is a relic parameter no longer used; CVs for maturation rates are hard coded in the program at 0.1).
5	Standard deviation about average age 3 maturation rate as estimated from CTC ER analysis (This is a relic parameter no longer used; CVs for maturation rates are hard coded in the program at 0.1).
6	Age 4 average maturation rate from CTC ER analysis (This is a relic parameter no longer used; CVs for maturation rates are hard coded in the program at 0.1).
7	Standard deviation about average age 4 maturation rate as estimated from CTC ER analysis

Appendix Table 3- 7. Sampling rate file specified in line 8 in Appendix Table 3- 1. (CSV format).

Line	Description
1	Header
2 to 6	Base CWT sampling rate for fisheries 1 to 5 for time period 1
7 to 11	Base CWT sampling rate for fisheries 1 to 5 for time period 2
12 to 16	Base CWT sampling rate for fisheries 1 to 5 for time period 3
17 to 32	Base CWT sampling rate for escapements for stocks1 to 16.

Appendix Table 3- 8. Coefficients of variation CSV file specified in line 9 in Appendix Table 3- 1.

Line	Description
1	Header
2	Number of lines to read, description
3	CV for age 2 cohort size, description
4	*Relic* data line – not used
5	CV for distribution of cohorts among fisheries, description
6	CVs for maturation rates (ages 2-4), description (This is a relic parameter no longer used. CVs for maturation rates are hard coded in the program at 0.1).
7	CV for sublegal release mortality rate, description
8	CV for drop off mortality rate, description
9 to 13	CVs for CWT sampling rate (by 3 time periods) for fisheries 1 to 5, description
14 to 29	CVs for CWT sampling rate in escapement for stocks 1 to 16

Appendix Table 3- 9. Annual catch distribution file specified in line 10 in Appendix Table 3- 1with information on four preterminal fisheries and fifth terminal fishery.

Line	Description
1	Header
2	Number of years specified, description
3+	Four sets of data, one for each preterminal fishery. The number of years=t, and the number of lines for each set of data are t+1.
Preterminal Line 1	Fishery number, description
Preterminal Line 2 to t+1	Year, proportion of annual catch by time period. Must sum to 1.0 over three time periods for each year.
Terminal Line 1	Header for terminal fishery
Terminal Line 2 to t+1	Year, terminal fishery harvest rate, and CV about harvest rate

Appendix Table 3- 10. HRI breakpoint CSV file specified in line 11 in Appendix Table 3- 1. Each of the four preterminal fisheries is modeled using three HRIs and two breakpoints. Abundance trigger levels were designed to generate HRI scalar values one-third of the time.

Line	**Description**
1	1st abundance trigger for fishery 1, description
2	2nd abundance trigger for fishery 1, description
3	1st abundance trigger for fishery 2, description
4	2nd abundance trigger for fishery 2, description
5	1st abundance trigger for fishery 3, description
6	2nd abundance trigger for fishery 3, description
7	1st abundance trigger for fishery 4, description
8	2nd abundance trigger for fishery 4, description

Scenario description

The two scenarios used for this report were designed to model a single transition from an “Old” to a “New” fishing pattern beginning in 1984 to mimic changes in the proportion of the annual catch taken by time period. The distribution of the total allowable annual catch (TAC) among time periods for the four preterminal fisheries is depicted in Appendix Table 3- 11.

Appendix Table 3- 11. Distribution of TAC among time periods for preterminal fisheries by year. After 1983, the fishery is closed in time period 3 (T3). Old regime was used in years (1979-1983) shaded in table.

	Fishery 1			**Fishery 2**			**Fishery 3**			**Fishery 4**		
Year	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
1979	0.05	0.11	0.84	0.03	0.30	0.67	0.13	0.34	0.53	0.13	0.34	0.53
1980	0.05	0.11	0.84	0.03	0.30	0.67	0.13	0.34	0.53	0.13	0.34	0.53
1981	0.05	0.11	0.84	0.03	0.30	0.67	0.13	0.34	0.53	0.13	0.34	0.53
1982	0.05	0.11	0.84	0.03	0.30	0.67	0.13	0.34	0.53	0.13	0.34	0.53
1983	0.05	0.11	0.84	0.03	0.30	0.67	0.13	0.34	0.53	0.13	0.34	0.53
1984	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1985	0.17	0.10	0.73	0.03	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1986	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1987	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1988	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1989	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1990	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1991	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1992	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1993	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1994	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1995	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1996	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00
1997	0.17	0.10	0.73	0.02	0.46	0.52	0.60	0.22	0.18	0.72	0.28	0.00

The second scenario differed from the first in the following ways:

- For fisheries 1 and 2, HRIs were reduced by 30% for all years.
- For fisheries 3 and 4, HRIs were reduced by 30% through 1983 and by 70% (of Scenario 1 level) from 1984. This is accomplished through the use of scalar parameters (equation App5-2).

HRI values are hard-coded in the Model in the FisheryDataClass in the file "FisheryData.VB." The Breakpoints, HRIs, and minimum abundance triggers used in the two model scenarios are specified in Appendix Table 3- 12.

A terminal fishery (Fishery 5) is included as a representative of terminal fisheries with a fixed harvest rate and with sampling for tags in both scenarios. No HRI is calculated for terminal fisheries with fixed harvest rates and no results on HRIs are therefore reported.

Appendix Table 3- 12. Breakpoints, HRIs and minimum abundance triggers used in two model scenarios.

Fish #	Brkpt #	Min Abund Trigger	HRI Scalars Scenario 1	HRI Scalar Scenario 2 (After 1983, values for previous years identical to Scenario 1)
1		0	6.25	4.375
1	1	113,085	7.50	5.250
1	2	118,660	8.00	5.600
2		0	5.00	3.500
2	1	60,300	6.25	4.375
2	2	66,185	7.50	5.250
3		0	1.50	0.750
3	1	88,835	3.00	1.500
3	2	101,500	4.50	2.250
4		0	1.50	0.750
4	1	88,835	3.00	1.500
4	2	101,500	4.50	2.250

By default, the Model starts each run in 1979. Alternative HRIs were evaluated using 25 replicates of two 19-year scenarios, with fisheries and escapements sampled for CWTs 10 times. Replicates provide information on variability due process error while multiple sampling for CWTs provides information on variability due to sampling error.

Because of the time required to perform the Monte Carlo simulations, the sheer volume of data produced by the model, and the effort required to generate estimates of alternative HRIs, data for only six years were used in the analysis. Catch years 1982 and 1983 were selected to provide data for the first two brood years that would complete their life cycles under the "Old" fishing pattern. Catch years 1991 and 1992 were selected to provide data for the first two brood years that would complete their life cycles under the "New" fishing pattern. Catch years 1985 and 1986 were selected to provide data for brood years that would be affected during the transition from the "Old" to "New" fishing patterns.

Annual simulation cycle

Time Period 1 (October-April). The fish are distributed to the four ocean fisheries, and an expected catch under base period ERs is generated for each preterminal fishery:

$$C_{f,y} = \sum_{s}\sum_{a} COH_{y,s,a,t=1} * PV_{s,a,t=1} * ER_{f,y,s,a} \qquad \text{(A.5-1)}$$

These expected catch values are compared with trigger levels for each fishery, the associated stepped HRI is determined, and a total annual allowable catch level is computed by:

$$TAC_{f,y} = HRI_{f,y} * hriScalar_{f,y} * \sum_{s}\sum_{a} COH_{y,s,a,t=1} * PV_{s,a,t=1} * ER_{f,y,s,a} \qquad \text{(A.5-2)}$$

The $hriScalar_{f,y}$ parameters are used to model changes in HRIs under scenario 2 and are hard-coded in the Harvest Rate simulator.

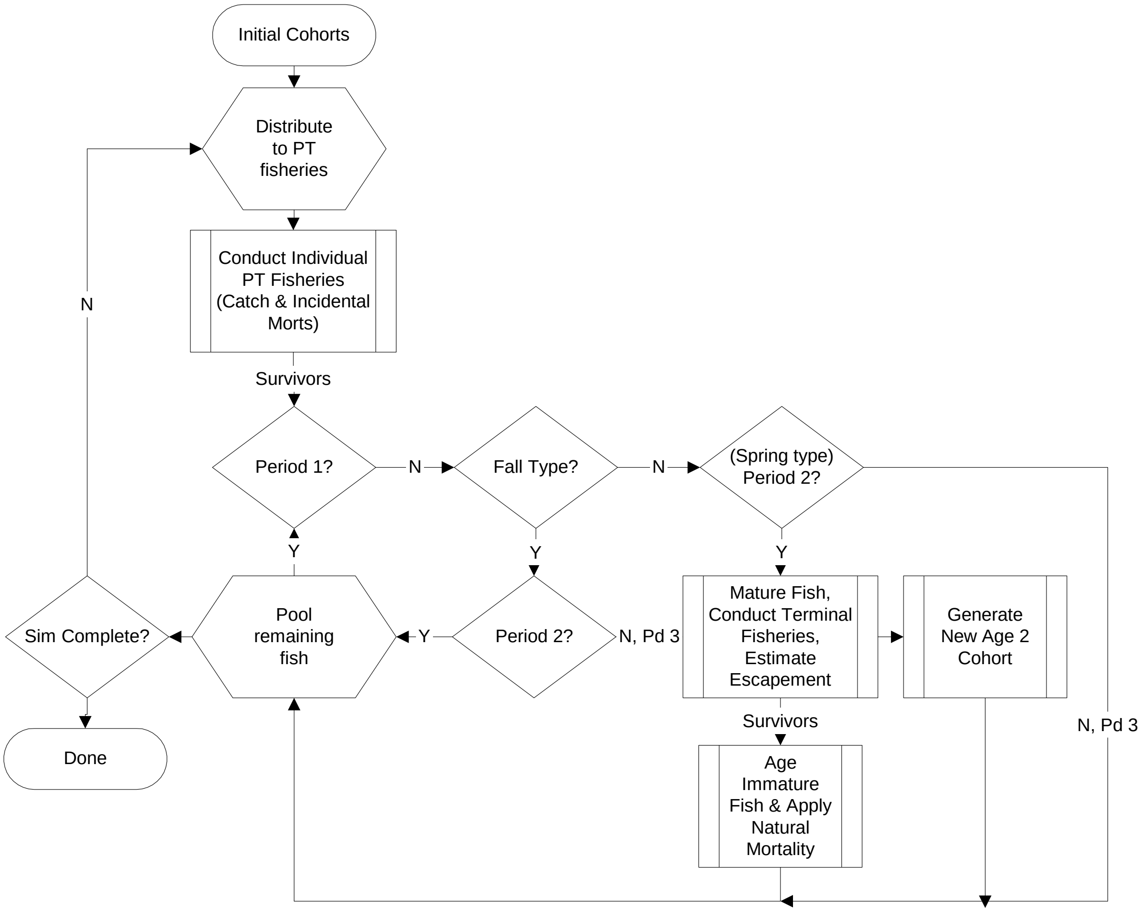
The TAC for a given fishery is then allocated among fishing periods according to a pre-determined fishing pattern (*TimeDist*).

$$TAC_{f,y} = \sum_t TAC_{f,y,t} = \sum_t TAC_{f,y} * TimeDist_{f,y,t} \qquad \text{(A.5-3)}$$

Preterminal fisheries are simulated as quotas so that the model continues simulating encounters of fish until the catch of legal sized fish allocated to time period 1 is taken. To simulate fishing, a fish is randomly encountered (hooked) by the gear. If the fish does not drop off, and is of legal size, it is landed, added to the total catch of the fishery, and subtracted from the available cohort. If it drops off, or is below the legal size limit, it is subject to incidental mortality. If it dies from incidental mortality, it is subtracted from the available cohort. If the encountered fish does not die, it remains in the available cohort and is immediately available for another encounter (no sulk time). This fishing process continues until the quota for that time/area is achieved.

<u>Time Period 2 (May-June).</u> The fish that survive after completion of preterminal fisheries in time period 1 are pooled and then redistributed among the four preterminal fisheries for time period 2. Fish are grown using stock-specific parameters. Fishing processes are modeled in the manner described for time period 1. Each preterminal fishery is simulated until the catch of legal sized fish allocated to time period 2 is taken. For spring type fish, adult fish are matured and subjected to terminal fishing, a new age 2 cohort is produced, and natural mortality is applied.

<u>Time Period 3 (July-Sept).</u> The fish surviving from preterminal fisheries in time period 2 are pooled and redistributed among the four preterminal fisheries. The fish are grown using stock-specific parameters. Fishing processes are modeled in the manner described for time period 1. Each preterminal fishery is simulated until the catch of legal sized fish allocated to time period 3 is taken. For fall type fish, adult fish are matured and subjected to terminal fishing, a new age 2 cohort is produced, and natural mortality is applied.



Appendix Figure 3- 2.. Annual cycle in Harvest Rate simulator.

Output file descriptions

Each run of the Harvest Rate Model is identified by a "runID" name. Each run produces three main CSV data files (a fourth file, *runIDAbundanceStats.PRN* is also produced, but is used only for Model debugging purposes).

- *runIDCatchSamples.CSV*
- *runIDMaturationRates.CSV*
- *runIDFisheryCatches.CSV*

A description of each of these CSV output files follows:

runIDCatchSamples.CSV contains cohort sizes and the number of tagged and untagged fish in catches and CWT samples by stock and age. Cohort analysis is performed for each CWT sample to estimate cohort sizes and ERs. The first line contains headers for column names, with data rows following (Appendix Table 3- 13).

Appendix Table 3- 13. Format of each data row in file *runIDCatchSamples.CSV*

Item	Description
1	runID
2	Simulation iteration number
3	Simulation year
4	CWT sample number
5	Time Period
6	Fishery Number
7	CWT sampling rate
8	Stock run type (Mislabeled in file)
9	Three letter Stock acronym (Mislabeled in file)
10	Stock number
11 to 14	Age 2 to 5 Observed CWT recoveries

runIDMaturationRates.CSV contains annual maturation rates produced by the Harvest Rate Simulator. Values of average maturation rates are computed from the data in this file. Average maturation rates are used in cohort analysis methods to estimate cohort sizes for incomplete broods. The first line contains headers for column names, with data rows following (Appendix Table 3- 14).

Appendix Table 3- 14. Format of each data row in file *runIDMaturationRates.CSV*

Item	Description
1	runID
2	Simulation iteration number
3	Simulation year
4	Three letter Stock acronym
5	Stock number
6 to 9	Age 2 to 5 simulated maturation rate

*runIDFisheryCatches.CSV c*ontains true numbers of tagged and untagged fish in catches and escapements. Data in this file are used to generate estimates of true exploitation and fishery harvest rates for comparison with alternative HRI metrics (Appendix Table 3-15). The first line contains headers for column names.

Appendix Table 3- 15. Format of each data row in file runIDFisheryCatches.*CSV*

Item	**Description**
1	runID
2	Simulation iteration number
3	Simulation year
4	CWT sample number
5	Time Period
6	Fishery Number
7	True harvest rate on vulnerable-sized fish
8	Stock run type (Mislabeled in file)
9	Three letter Stock acronym (Mislabeled in file)
10	Stock number
11 to 14	Age 2 to 5 Cohort Size for fish without CWTs
15 to 18	Age 2 to 5 Retained catch for fish without CWTs
19 to 22	Age 2 to 5 Incidental Mortality for fish without CWTs
23 to 26	Age 2 to 5 Cohort Size for fish with CWTs
27 to 30	Age 2 to 5 Retained catch for fish with CWTs
31 to 34	Age 2 to 5 Incidental Mortality for fish with CWTs
35 to 38	Age 2 to 5 adult equivalence factor

Appendix 4. Output formats from cohort analysis

Selected data elements are output in a file format designed to expedite computation of fishery HRIs with a single file output for each iteration, CWT sample and fishery with estimates for observed and estimated tags, ERs and cohort sizes (Appendix Table 4- 1). Each iteration, sample and fishery was output to a separate file, with the file name *runidSIMnoSAMnoFISHno.CSV* where SIM is the iteration number within the run, SAM the sample number within the iteration and FISH the fishery number. Detailed results of the cohort analyses performed using data for both complete and incomplete broods are output in file *MONSTER.CSV* (Appendix Table 4- 2) where observed and estimated tagged fish, estimated incidental mortalities, ERs, terminal run, cohort sizes and maturation rates are output for all iterations, samples and catch years. The cohort analysis program generates estimates of AEQs and maturation rates in file *MATRATESAEQ.CSV* (Appendix Table 4- 3) and PNVs in file *PNV.CSV* (Appendix Table 4- 4).

Appendix Table 4- 1. Format for output data file *runidSIMnoSAMnoFISHno.CSV* output from the cohort analysis program. This file contains results for the cohort analysis for a single iteration, sample and fishery for six catch years, 1982, 1983, 1985, 1986, 1991 and 1992.

Column Name	**Description**
SimID	Name of simulation model run
Iter	Iteration number
Sam no	Sample number
Stock no	Stock Number
Stock Type	Stock type (spring or fall)
Fishery	Fishery number (1-6); Fishery 6 is escapement
Catch Year	Catch Year
Per	Time Period number (1-3)
Age 2 Obs	Number of CWTs recovered for age 2
Age 3 Obs	Number of CWTs recovered for age 3
Age 4 Obs	Number of CWTs recovered for age 4
Age 5 Obs	Number of CWTs recovered for age 2
Age 2 CWT	Estimated number of CWTs for age 2
Age 3 CWT	Estimated number of CWTs for age 3
Age 4 CWT	Estimated number of CWTs for age 4
Age 5 CWT	Estimated number of CWTs for age 5
Age 2 ER 1	Incomplete estimate of ER for age 2 in catch year based recoveries of age 2 fish
Age 2 ER 2	Incomplete estimate of ER for age 2 in catch year + 1 based recoveries of age 2 and 3 fish
Age 2 ER 3	Incomplete estimate of ER for age 2 in catch year + 2 based recoveries of age 2, 3 and 4 fish

Appendix Table 4- 1. Format for output data file *runidSIMnoSAMnoFISHno.CSV* output from the cohort analysis program. This file contains results for the cohort analysis for a single iteration, sample and fishery for six catch years, 1982, 1983, 1985, 1986, 1991 and 1992.

Column Name	**Description**
Age 2 ER C	Complete estimate of ER for age 2 in catch year + 3 based recoveries of age 2-5 fish
Age 3 ER 1	Incomplete estimate of ER for age 3 in catch year based recoveries of 3 fish.
Age 3 ER 2	Incomplete estimate of ER for age 3 in catch year + 1 based recoveries of age 2-4 fish
Age 3 ER C	Complete estimate of ER for age 3 in catch year + 2 based recoveries of age 3-5 fish
Age 4 ER 1	Incomplete estimate of ER for age 4 in catch year based on recoveries of age 4 fish.
Age 4 ER C	Complete estimate of ER for age 4 in catch year +1 based recoveries of age 4-5 fish
Age 5 ER C	Complete estimate of ER for age 5 in catch year based recoveries of age 5 fish alone.
Age 2 COH 1	Incomplete estimate of cohort size for age 2 in catch year based recoveries of age 2 fish
Age 2 COH 2	Incomplete estimate cohort size for age 2 in catch year + 1 based recoveries of age 2 and 3 fish
Age 2 COH 3	Incomplete estimate cohort size for age 2 in catch year + 2 based recoveries of age 2, 3 and 4 fish
Age 2 COH C	Complete estimate cohort size for age 2 in catch year + 3 based recoveries of age 2-5 fish
Age 3 COH 1	Incomplete estimate cohort size for age 3 in catch year based recoveries of age 3 fish.
Age 3 COH 2	Incomplete estimate cohort size for age 3 in catch year + 1 based recoveries of age 3 and 4 fish
Age 3 COH C	Complete estimate cohort size for age 3 in catch year + 2 based recoveries of age 3-5 fish
Age 4 COH 1	Incomplete estimate cohort size for age 4 in catch year based recoveries of age 4 fish.
Age 4 COH C	Complete estimate cohort size for age 4 in catch year + 1 based recoveries of age 4 and 5 fish
Age 5 COH C	Complete estimate cohort size for age 5 in catch year based recoveries of age 5 fish.

Appendix Table 4- 2. Format for output data file MONSTER.CSV output from the cohort analysis program. This file contains all of the results for the cohort analysis.

Column Name	**Description**
SimID	Name of simulation model run
Iter	Iteration number
Sam no	Sample number
Stock no	Stock Number
Stock Type	Stock type (spring or fall)
Fishery	Fishery number (1-6); Fishery 6 is escapement
Catch Year	Catch Year
Per	Time Period number (1-3)
Age 2 Obs	Number of CWTs recovered for age 2
Age 3 Obs	Number of CWTs recovered for age 3
Age 4 Obs	Number of CWTs recovered for age 4
Age 5 Obs	Number of CWTs recovered for age 2
Age 2 CWT	Estimated number of CWTs for age 2
Age 3 CWT	Estimated number of CWTs for age 3
Age 4 CWT	Estimated number of CWTs for age 4
Age 5 CWT	Estimated number of CWTs for age 5
Age 2 INC	Estimated number of incidental mortalities (sublegal and dropoff) for age 2
Age 3 INC	Estimated number of incidental mortalities (sublegal and dropoff) for age 3
Age 4 INC	Estimated number of incidental mortalities (sublegal and dropoff) for age 4
Age 5 INC	Estimated number of incidental mortalities (sublegal and dropoff) for age 5
Age 2 ER 1	Incomplete estimate of ER for age 2 in catch year based recoveries of age 2 fish
Age 2 ER 2	Incomplete estimate of ER for age 2 in catch year + 1 based recoveries of age 2 and 3 fish
Age 2 ER 3	Incomplete estimate of ER for age 2 in catch year + 2 based recoveries of age 2, 3 and 4 fish
Age 2 ER C	Complete estimate of ER for age 2 in catch year + 3 based recoveries of age 2-5 fish
Age 3 ER 1	Incomplete estimate of ER for age 3 in catch year based recoveries of 3 fish.
Age 3 ER 2	Incomplete estimate of ER for age 3 in catch year + 1 based recoveries of age 2-4 fish
Age 3 ER C	Complete estimate of ER for age 3 in catch year + 2 based recoveries of age 3-5 fish
Age 4 ER 1	Incomplete estimate of ER for age 4 in catch year based on recoveries of age 4 fish.

Appendix Table 4- 2. Format for output data file MONSTER.CSV output from the cohort analysis program. This file contains all of the results for the cohort analysis.

Column Name	Description
Age 4 ER C	Complete estimate of ER for age 4 in catch year +1 based recoveries of age 4-5 fish
Age 5 ER C	Complete estimate of ER for age 5 in catch year based recoveries of age 5 fish alone.
Age 2 COH 1	Incomplete estimate of cohort size for age 2 in catch year based recoveries of age 2 fish
Age 2 COH 2	Incomplete estimate cohort size for age 2 in catch year + 1 based recoveries of age 2 and 3 fish
Age 2 COH 3	Incomplete estimate cohort size for age 2 in catch year + 2 based recoveries of age 2, 3 and 4 fish
Age 2 COH C	Complete estimate cohort size for age 2 in catch year + 3 based recoveries of age 2-5 fish
Age 3 COH 1	Incomplete estimate cohort size for age 3 in catch year based recoveries of age 3 fish.
Age 3 COH 2	Incomplete estimate cohort size for age 3 in catch year + 1 based recoveries of age 3 and 4 fish
Age 3 COH C	Complete estimate cohort size for age 3 in catch year + 2 based recoveries of age 3-5 fish
Age 4 COH 1	Incomplete estimate cohort size for age 4 in catch year based recoveries of age 4 fish.
Age 4 COH C	Complete estimate cohort size for age 4 in catch year + 1 based recoveries of age 4 and 5 fish
Age 5 COH C	Complete estimate cohort size for age 5 in catch year based recoveries of age 5 fish.
Age 2 MATR 1	Average maturation rate from MATRATES.SIM output from HRI simulation program used for estimate of cohort size for age 2 in catch year
Age 2 MATR 2	Estimate of maturation rate for age 2 in catch year + 1 based on recoveries of age 2 and 3 fish
Age 2 MATR 3	Estimate of maturation rate for age 2 in catch year + 2 based on recoveries of age 2, 3 and 4 fish
Age 2 MATR C	Estimate of maturation rate for age 2 in catch year + 3 based on recoveries of age 2-5 fish
Age 3 MATR 1	Average maturation rate from MATRATES.SIM output from HRI simulation program used for estimate of cohort size for age 3 in catch year
Age 3 MATR 2	Estimate of maturation rate for age 3 in catch year + 1 based on recoveries of age 3 and 4 fish
Age 3 MATR C	Estimate of maturation rate for age 3 in catch year + 2 based on recoveries of age 3-5 fish

Appendix Table 4- 2. Format for output data file MONSTER.CSV output from the cohort analysis program. This file contains all of the results for the cohort analysis.

Column Name	Description
Age 4 MATR 1	Average maturation rate from MATRATES.SIM output from HRI simulation program used for estimate of cohort size for age 4 in catch year
Age 4 MATR C	Estimate of maturation rate for age 4 in catch year + 1 based on recoveries of age 4 and 5 fish
Age 5 MATR C	Estimate of maturation rate for age 5 in catch year based on recoveries of age 5 fish. Age 5 maturation rate always set at 1.

Appendix Table 4- 3. Format for output data file *MATRATESAEQ.CSV* containing maturation rates and AEQs by catch year, stock and age. Note that the first incomplete estimate of maturation rates for each age is the average of the maturation rates output from the HRI simulation program.

Column Name	Description
SimID	Name of simulation model run
Iter	Iteration number
Catch Year	Catch Year
Stock no	Stock Number
Matrate Age 2 Est1	Average maturation rate from MATRATES.SIM used to estimate cohort size for age 2 in catch year
Matrate Age 2 Est2	Estimate of maturation rate for age 2 in year 2 based on recoveries of age 2 and 3 fish
Matrate Age 2 Est3	Estimate of maturation rate for age 2 in year 3 based on recoveries of age 2, 3 and 4 fish
Matrate Age 2 Com	Complete estimate of maturation rate for age 2 in year 4 based on recoveries of age 2-5 fish
Matrate Age 3 Est1	Average maturation rate from MATRATES.SIM used to estimate cohort size for age 3 in catch year
Matrate Age 3 Est2	Estimate of maturation rate for age 3 in year 2 based on recoveries of age 3-4 fish
Matrate Age 3 Com	Complete estimate of maturation rate for age 3 in year 3 based on recoveries of age 3-5 fish
Matrate Age 4 Est1	Average maturation rate from MATRATES.SIM used to estimate cohort size for age 4 in catch year
Matrate Age 4 Com	Complete estimate of maturation rate for age 4 in year 2 based on recoveries of age 4-5 fish
Matrate Age 5 Com	Complete estimate of maturation rate for age 5 in year 1 based on recoveries of age 5 fish
AEQ Age 2	Adult equivalent factor calculated for age 2 based on complete data for age 2-5
AEQ Age 3	Adult equivalent factor calculated for age 3 based on complete data for age 3-5

Appendix Table 4- 3. Format for output data file *MATRATESAEQ.CSV* containing maturation rates and AEQs by catch year, stock and age. Note that the first incomplete estimate of maturation rates for each age is the average of the maturation rates output from the HRI simulation program.

Column Name	Description
AEQ Age 4	Adult equivalent factor calculated for age 2 based on complete data for age 4-5
AEQ Age 5	Adult equivalent factor calculated for age 5, always 1.

Appendix Table 4- 4. Format for output data file PNV.CSV containing estimated proportion not vulnerable by stock, fishery and period. These estimates are derived using data input from file *LENGTHATAGE.SIM*.

Column Name	Description
SimID	Name of simulation model run
Iter	Iteration number
Sample no	Sample number
Stock no	Stock Number
Period	Time Period
Fishery	Fishery Number
PNV age 2	Estimate of proportion not vulnerable by fishery and time period for age 2
PNV age 3	Estimate of proportion not vulnerable by fishery and time period for age 3
PNV age 4	Estimate of proportion not vulnerable by fishery and time period for age 4
PNV age 5	Estimate of proportion not vulnerable by fishery and time period for age 5

Appendix 5. Bootstrap Analysis of SPFI

The formulation of the SPFI requires both CWT recoveries in a stratum as well as landed catch in order to produce an estimate of harvest rate for the year in which the stratum occurs. The overall abundance in a stratum is calculated as the landed catch in the stratum divided by the stratum specific harvest rate as estimated by CWTs. This abundance estimate is needed for all strata in any particular year in order to calculate a total yearly abundance and to subsequently estimate the overall fishery harvest rate for that year.

Three time specific strata have been proposed for use in constructing a SPFI for the WCVI troll fishery. However, there are several instances where either no catch occurs in a particular stratum for a particular year or where the catch is so small that insufficient CWT recoveries occur. A method has been proposed to estimate the total yearly abundance for years that contain a stratum where there is no landed catch, no CWT recoveries or both. The method, hereafter referred to as the Strata Percentage or SP method, uses information from all years without missing strata information to obtain the average percentage of the total yearly abundance that is present in each stratum. These percentages are used to estimate the total yearly abundance for years with missing data. For years in which one or more strata contain no catch or CWT recoveries, the abundance from the strata with CWT recoveries are summed and then divided by the average proportion of the total yearly abundance that those strata comprise.

In order to test how well the SP method would work in estimating yearly SPFI values for years in which there was missing catch and/or missing CWT data, a bootstrap analysis was performed using data from the Alaska troll fishery. The Alaska troll fishery SPFI uses 5 yearly time-area strata. In the current time series of information for the Alaska troll fishery, there are no years with missing catch or CWT information in any strata. Therefore, by zeroing out catch and CWT information in certain strata and applying the SP method to estimate the total yearly abundance, the resulting estimated yearly SPFI value can be compared to the yearly SPFI value based on the catch and CWT information using all strata.

Catch and CWT recoveries from the Alaska troll fishery for the years 1979 to 2005 were used in a bootstrap simulation as follows. Years outside of the 1979 to 1982 base period were chosen randomly with each year having a 20% chance of being chosen. For each year one of the 5 strata was chosen at random where each stratum had an equal probability of being chosen. The catch and estimated number of CWT recoveries for the selected stratum were set to zero. The total yearly abundance for the year in question was then estimated by dividing the sum of the abundances in the remaining strata by the average percentage of the total yearly abundance that those strata comprised as estimated from all other years in which a stratum was not zeroed out. This process was repeated 10,000 times and the resulting differences (estimated SPFIs using the APC method minus the corresponding actual SPFIs using the data from all strata and denoted as $\Delta SPFI$) were calculated for all iterations and all years that contained a stratum with catch and recovery data set to zero. A confidence interval was constructed from the $\Delta SPFI$ values based on the normal distribution. The point estimate of the mean for $\Delta SPFI$ was 0.0036 with a variance of 0.0028 and a 95% confidence interval of (0.0031, 0.0041). The confidence interval was computed as follows:

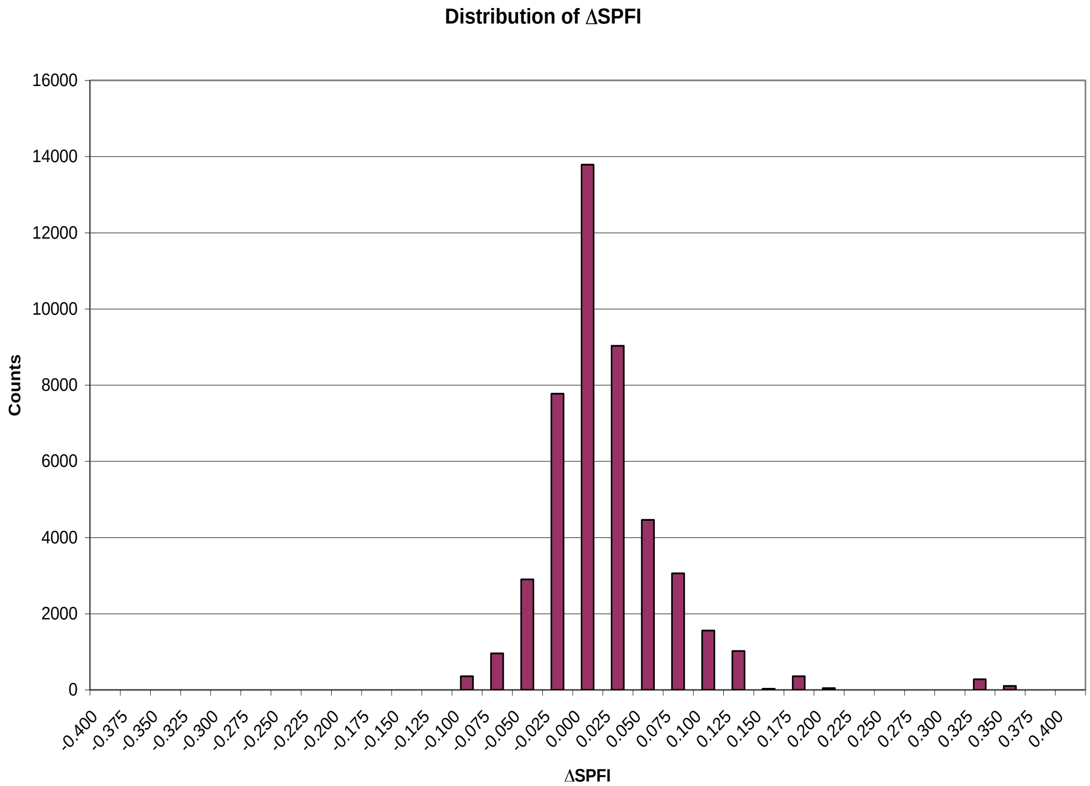
$$\mu \pm Z_{0.05}\sqrt{\frac{S^2}{n}} = 0.0036 \pm 1.96\sqrt{\frac{0.0028}{45{,}718}} \qquad \text{(A.4-1)}$$

The Z statistic was substituted for the T statistic since the sample size was very large (n=45,718). Since the interval did not encompass zero, there was evidence of a slight bias in using the SP method to estimate the actual SPFI value. However, since the bias was small the actual effect on the average SPFI estimate would be negligible. The average relative error between the estimated SPFIs and the actual SPFIs was 0.082. Maybe of greater interest is the prediction interval for a future SPFI estimate based on the SP method. The 95% prediction interval for $\Delta SPFI$ is (-0.1003, 0.1075) which indicates that 95% of future SPFI estimates using the SP method would be within approximately plus or minus 0.1 of the actual SPFI value. The prediction interval was computed as follows:

$$\mu \pm Z_{0.05}\sqrt{S^2\left(1+\frac{1}{n}\right)} = 0.0036 \pm 1.96\sqrt{0.0028\left(1+\frac{1}{45{,}718}\right)} \qquad \text{(A.4-2)}$$

The distribution of the $\Delta SPFI$ values from the bootstrap analysis can be seen in Appendix Figure 4-1.

It must be noted that this analyses was performed by zeroing out the catch and CWT recoveries for only one of the five Alaska troll fishery strata in the randomly chosen years. If the catch and CWT recoveries had been zeroed out in more than one stratum in a single year it is quite likely that the variance of the $\Delta SPFI$ values would increase. The possible effect on the bias is unknown. The effect of zeroing out the catch and CWT recoveries for differing numbers of strata in randomly chosen years would be a good avenue of further study and could provide insight in to how many intact strata are necessary to provide reliable SPFI estimates.



Appendix Figure 5- 1 . Distribution of the 45,718 $\Delta SPFI$ values generated from the 10,000 bootstrap iterations.