2004-2006 US LOA CHINOOK DRAFT REPORT

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TO:

U.S. CHINOOK TECHNICAL COMMITTEE,
&
Dave Cantillon, NOAA, NMFS, Sandpoint, Seattle, USA

SUBMITTED BY:

Rishi Sharma,
Columbia River Inter-Tribal Fish Commission (CRITFC), Suite 200,
729 NE Oregon St., Portland, OREGON, 97232

PROJECT TITLE

Fixes or Alternatives to the Individual Stock Based Management (ISBM) provisions

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EXECUTIVE SUMMARY

This report covers alternatives to the current approach used to generate Individual Stock Based Management (ISBM) indices. As shown by Sharma (2005), there are numerous problems with the current index. These stem from the fact that the model and coded-wire tagged (CWT) based indices do not track each other. Biases were large across most stocks (Sharma 2005) and the index was instable due to an incomplete brood effect. Besides these issues, a lag-time for two years existed before any evaluation was possible, because CWT reporting lagged by two years, and finally the overall coverage of CWT's to represent different stocks is poor.

This report identifies some alternatives to current status quo. These alternatives correct for some of the problems identified above, but still have issues regarding the latter two points poor CWT coverage and a lag effect of two years before an evaluation is possible. Possible alternatives include:

1. Using CWT projections based on effort, survival and release data to compute the following:
    - i) Preseason ISBM indices on tag projections and comparing them with CWT data using the current pass through index calculations.
    - ii) Computing a new index based on base period release, survival and effort data and relating that to the current predicted response.
2. Computing a composite index across fisheries and relating the composite to escapements of different stocks. This relationship would then determine a level of composite exploitation across fisheries that would meet target escapement objectives of a stock or group of stocks.
3. Effort based indices that compute instantaneous fishing mortality rates. Some variants of this approach are:
    - (i) Effort based indices accounting for gear selectivity and catchability.
    - (ii) Computing a new index based on base period selectivity, catchability, and effort data and relating that to the current predicted response, &
    - (iii) Moving away from an index to managing by Exploitation rates by fishery or groups of fisheries as the catch at age model would provide these estimates.

A feasibility study was conducted with the Priest Rapids indicator tag code of the Columbia Upriver Bright stocks to estimate the indices by the three methods identified above. Method 2 requires a completely new way of doing management and is probably not feasible for the short term. In addition, the data do not support method 2 formulation for some stocks. The results of the other two methods (1 and 3) are shown in Figure (1) and Tables 1 and 2 below across the various methods.

The methods all show similar trends (Figure 1). Pre-and post season tracking determined that certain methods (namely the corrected estimates 1(b) and 3(b)) perform substantially better than the current status quo. The method 1(i), 1(ii) and 3(ii) indicates relatively low bias over the entire time period when we evaluate pre- and post-season indices for the Upriver Bright stock.

Table 1: US ISBM Indices using the current (status quo) and alternative methods

Calendar Year	Status Quo Method 1(a) corrected pre-pseason	Status Quo Method 1(a) corrected post-pseason	Method 1(b): CWT effort projection Index (pre)	Method 1(b): CWT effort projection Index (post)	SCAA Method 3(a): Effort Index	Method 3(b): SCAA CWT effort projection Index (pre)	Method 3(b): CWT effort projection Index (post)	SCAA Method 3 (c): ERA in US PT ISBM fishery	SCAA Method 3 (c): ERA in US terminal ISBM fishery
1983	1.22	0.58	0.45	0.15	0.52	0.29	0.15	0.01	0.21
1984	1.45	1.36	0.63	0.67	0.69	1.11	0.67	0.01	0.53
1985	1.72	2.14	1.81	2.67	1.26	2.26	2.67	0.02	0.44
1986	2.12	1.88	2.74	3.72	1.80	3.86	3.72	0.02	0.50
1987	2.23	2.68	2.40	2.89	2.10	3.17	2.89	0.02	0.50
1988	2.21	2.79	1.96	2.77	2.52	2.25	2.77	0.02	0.47
1989	2.08	3.15	0.87	1.19	3.09	1.30	1.19	0.02	0.50
1990	1.89	2.88	0.45	0.53	2.06	0.39	0.53	0.02	0.45
1991	2.03	1.73	0.42	0.14	0.90	0.16	0.14	0.01	0.38
1992	1.71	1.20	0.37	0.15	0.75	0.20	0.15	0.01	0.38
1993	1.51	1.34	0.39	0.26	1.17	0.34	0.26	0.01	0.32
1994	1.54	1.01	0.42	0.33	0.60	0.17	0.33	0.00	0.12
1995	1.29	1.14	0.29	0.22	0.29	0.10	0.22	0.01	0.10
1996	0.99	1.23	0.31	0.46	0.99	0.31	0.46	0.00	0.26
1997	0.97	1.59	0.31	0.69	0.79	0.49	0.69	0.01	0.28
1998	1.33	1.16	0.41	0.31	0.66	0.33	0.31	0.00	0.22
1999	1.40	1.18	0.50	0.73	1.25	0.69	0.73	0.00	0.31
2000	1.19	1.79	0.50	0.58	0.59	0.55	0.58	0.00	0.28
2001	1.46	1.16	1.13	0.84	0.81	0.85	0.84	0.01	0.34
2002	1.51	1.39	1.42	1.32	1.38	1.34	1.32	0.01	0.32
2003	1.74	1.38	1.67	1.10	1.03	1.37	1.10	0.01	0.37
2004	1.14	1.52	1.52	1.38	0.92	1.13	1.38	0.01	0.35

Table 2: Canadian ISBM Indices using the current (status quo) alternative methods.

Calendar Year	Status Quo Method 1(a) corrected pre-season	Status Quo Method 1(a) corrected	Method 1(b): CWT effort projection Index (pre)	Method 1(b): CWT effort projection Index (post)	SCAA Method 3(a): Effort Index	Method 3(b): SCAA CWT effort projection Index (pre)	Method 3(b): CWT effort projection Index (post)	SCAA Method 3 (c): ERA in Canadian ISBM fishery
1983	0.54	0.58	0.21	0.33	0.72	0.28	0.33	0.024
1984	0.76	1.36	0.46	0.51	0.89	0.63	0.51	0.029
1985	0.45	2.14	0.41	0.67	0.91	0.64	0.67	0.030
1986	0.37	1.88	0.45	0.65	0.83	0.83	0.65	0.028
1987	0.31	2.68	0.29	0.49	0.59	0.58	0.49	0.020
1988	0.22	2.79	0.17	0.16	0.47	0.27	0.16	0.016
1989	0.41	3.15	0.13	0.13	0.60	0.25	0.13	0.020
1990	0.30	2.88	0.07	0.05	0.54	0.08	0.05	0.018
1991	0.31	1.73	0.06	0.00	0.55	0.05	0.00	0.018
1992	0.31	1.20	0.07	0.05	0.57	0.06	0.05	0.019
1993	0.31	1.34	0.08	0.02	0.52	0.07	0.02	0.017
1994	0.26	1.01	0.06	0.12	0.36	0.06	0.12	0.012
1995	0.27	1.14	0.05	0.02	0.24	0.05	0.02	0.008
1996	0.22	1.23	0.05	0.02	0.41	0.05	0.02	0.014
1997	0.21	1.59	0.06	0.04	0.43	0.07	0.04	0.014
1998	0.24	1.16	0.06	0.02	0.32	0.08	0.02	0.011
1999	0.19	1.18	0.07	0.09	0.35	0.07	0.09	0.012
2000	0.21	1.79	0.09	0.02	0.24	0.07	0.02	0.008
2001	0.19	1.16	0.13	0.07	0.29	0.08	0.07	0.010
2002	0.23	1.39	0.19	0.15	0.38	0.16	0.15	0.013
2003	0.19	1.38	0.22	0.37	0.43	0.20	0.37	0.014
2004	0.05	1.52	0.24	0.28	0.56	0.24	0.28	0.018

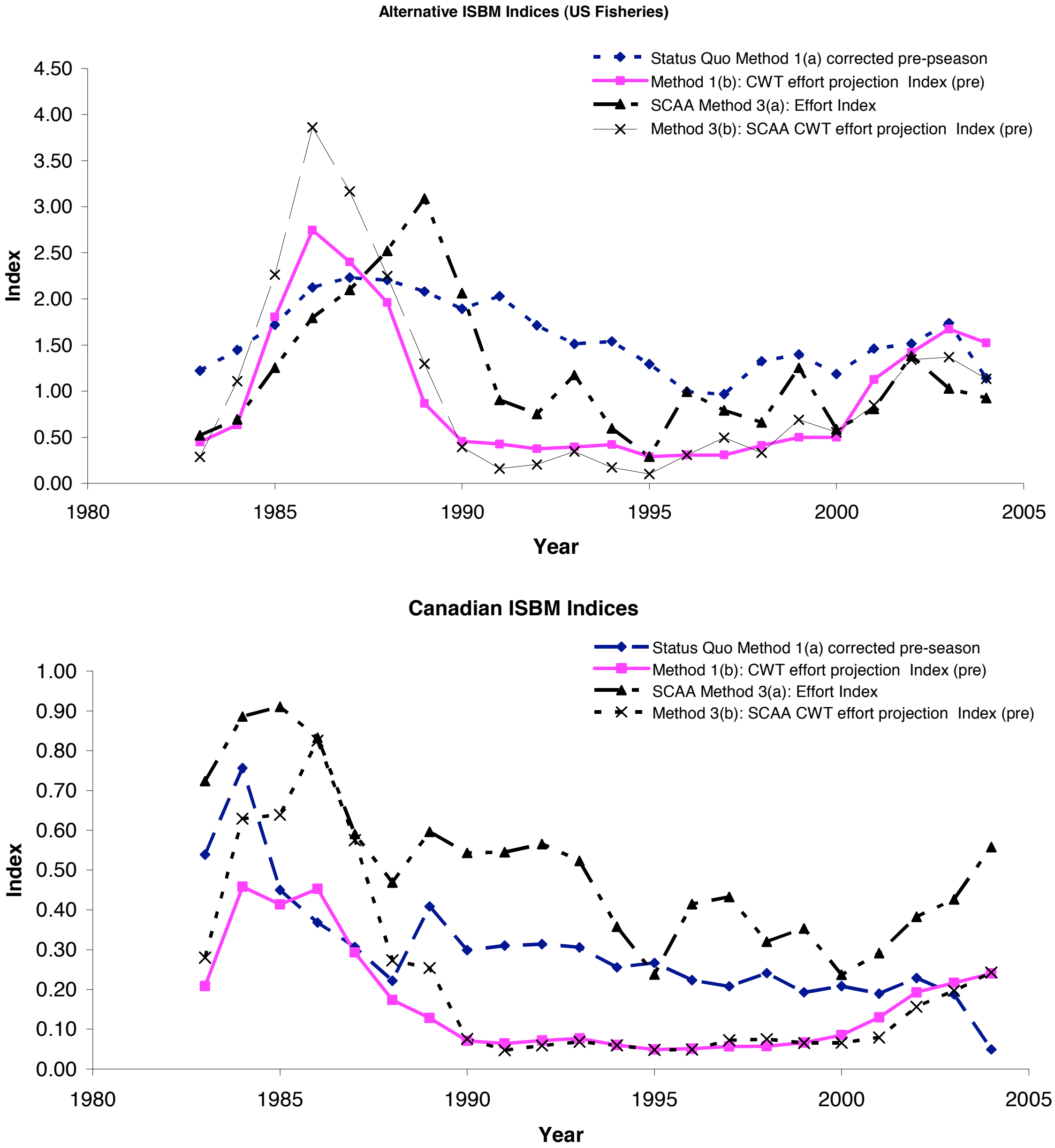


Figure 1: Alternative Indices for ISBM Management for Upriver Bright Chinook

The ISBM was largely developed to track problems with meeting escapement as a function of terminal and pre-terminal fisheries having a large harvest impact on that stock. In order to get this provision to work, the index should be rectified to work prospectively rather than using a preseason approach. Notifications to the salmon commission can then be made if some stock did not meet its goals and if some groups of fisheries were catching more than the specified limits. This is the track that the Chinook Technical Committee (CTC) recommended using with overage and underage provisions, and a similar approach should likely be taken with the ISBM index.

If the abovementioned approach is not possible, then the index should be modified to use only stocks that have tags that represent broader regions. Making a simplified index using the tag data, and expanding it for different geographical regions is the best that the current ISBM index is capable of doing, and should be limited to that at most. A simplified index would thus track exploitation for broad geographical locations such as the lower Columbia, upper Columbia, Oregon Coast, Washington coast, Puget Sound, lower and upper Fraser, and the west coast of Vancouver Island. There may be differences for stocks in close proximity to one another, but unless there is data to support these differences, it is pointless to generate indices for numerous stocks.

Finally, the purpose of the ISBM index is to insure that most stocks that are of concern and importance in the Pacific Salmon Treaty process are not over-fished. Since terminal and near terminal area fisheries have a direct relationship with overall stock exploitation (more so than mixed stock ocean fisheries), it may be more appropriate to track overall abundance and run size in terminal and near-terminal areas as the season progresses. Such approaches are commonly used in Bristol Bay, and could also be applied to terminal areas and near terminal areas and may be the best way to proceed over the long-term,.

1 INTRODUCTION

1.1 BACKGROUND

In 2003, some members of the Chinook Technical Committee raised questions regarding the implementation of the Individual Stock Based Management (ISBM) provision of the Chinook chapter of Annex IV of the U.S.-Canada Pacific Salmon Treaty. Consequently, a review of the implementation and application of the ISBM provision was identified as a high priority item with regard to the Chinook Letter of Agreement (LOA) funding.

A previous report on the ISBM index (Sharma 2005) delivered last year had two primary objectives. They were:

1. To document the source of data that are used to compute the ISBM indices for each of the stocks identified in the Chinook chapter.
2. To document the algorithms used in computing the indices pre- and post-season for each of these stocks, and the procedures used for extracting the data from the Chinook Technical Committee's Chinook model or from coded wire tag (CWT) data.

A third objective was to identify problems with these indices. Initially the identification of problems with the indices was to be part of a second phase report along with proposed recommendations or alternatives designed to address these problems, but these were addressed in last years report as well. Several limitations for the use of ISBM indices pre and post-season were identified by Sharma (2005):

- Logistical problems on data reporting exist as the model based indices are followed by post-season evaluation using coded wire tags (CWT's) two years later. Tagged data takes a while to process and input into the centralized data base, Regional Mark Information System (RMIS). As a result, if a stock fails to meet its escapement goal, it is not until two years after the fisheries have occurred that we can assess whether the target ISBM objectives established by the 1999 Agreement were met.

- A pre-season versus post-season analysis was performed on stocks which had both sets of data. Because some stocks in Canada have only one index for 5-7 stocks (e.g. WCVI (7) & Upper Georgia Straits (5)) a total of 19 stock composites out of a possible 41 stockswere analyzed. The indices tracked one another fairly consistently but in some cases (Green River, Washington coastal stocks, Oregon coastal stocks, Cowichan and Upper Georgia Straits) pre-season and post-season ISBM indexes had correlation coefficients that were negative. For the same identified stocks, the post season versus pre-season data were highly biased. For most Canadian stocks, Columbia River (other than Columbia Upriver Summers and Columbia Up River Brights (URBs)), and Oregon coastal stocks, the bias was negative indicating that the post-season evaluation (based on CWT recoveries in fisheries) was generally lower than the pre-season estimate. However, in the case of Washington coastal stocks, Columbia Upriver Summers, Columbia Upriver Brights and the Green River stock, the bias was positive indicating that the post-season estimates were generally higher than the pre-season estimate of the index. However, this is not a concern so long as the escapement goal for each stock is achieved by managers.

- CWT data coverage was generally poor for most stocks and numerous assumptions had to be made to associate different ISBM stocks with other CWT stock exploitation rates in the current year. To compound this issue, on stocks where data were available, the base period data coverage was poor. Only six out of forty-one stocks have complete coverage (CWT data associated with the stock of concern), while twenty stocks had indirect coverage associated with another tag code from a system meant to represent the geographical area with an adjustment made to the extreme terminal area harvest rates. Finally, eight stocks had issues with base period data coverage and seven stocks had no post season tag codes associated with them so that the CTC Chinook model had to be used to assess performance relative to the ISBM indices.

- Using adult equivalence on incomplete broods as part of the assessment process resulted in a downward bias of the estimated index. This index only stabilizes when all years in the index have a complete brood and this could thus take even longer than the two year lag.

A more detailed analysis is provided in Appendix 1 (taken from Sharma 2005) for reference.

Evaluating possible alternatives to the use of ISBM indices pre and post-season using feasibility analysis is the primary objective of this report (2006-2007 cycle).This report investigates techniques that might work with the existing structure, and also examines using alternative data frameworks. I conducted a feasibility analysis of three alternatives. One approach was evaluated using both the the existing structure and a new data framework. The other two approaches utilize new techniques and data structures. They are:

1. Using CWT projections based on effort, survival and release data to compute the following:
    i) Preseason ISBM indices on tag projections and comparing them with CWT data using the current pass through index calculations.
    ii) Computing a new index based on base period release, survival and effort data and relating that to the current predicted response
2) Computing a composite index across fisheries and relating the composite to escapement of different stocks, and thus determine a level of composite exploitation across fisheries that would meet target escapement objectives.
3) Compute instantaneous fishing mortality rates using effort based indices.

2 APPROACHES TO USE WITH THE CURRENT FRAMEWORK

2.1 CODED WIRE TAG BASED APPROACHES

To verify the current approach (validate) using coded wire tags, it may be necessary to estimate the tagged contributions based on fishery regulations to ISBM strata of fisheries. A historic time series of catch can also be used to determine if we can predict the tag contribution rates for those fisheries using simple Binomial models, log-linear models, or Poisson count models to predict the count (Neter et. al. 1996)

Historic recovery distributions of tags could serve as a predictor of future recovery and exploitation rates if assumptions are made about the recoveries by various strata (e.g. stock, age, gear and fishery strata) using a binomial probability model. Presently this and other log-linear models have been developed to analyze recovery data (Green and Macdonald 1987, Cormack and Skalski 1992). However, the use of these models is limited if fishing, sampling effort and environmental variability are not taken into account (Bernard and Clark 1996).

I estimated tag recovery rates from Priest Rapids Hatchery Upriver Bright (URB) fall Chinook stock indicator tag codes using a catch index as a measure of effort in ocean fisheries, and boat days as a measure for effort in river. Columbia URB stocks are typically ocean-type Chinook that spawn in the mainstem of the Columbia River above McNary Dam and in the Snake River.

I forecast 3 categories, namely Canadian ISBM fisheries, US ISBM fisheries, and other ocean fisheries by age and used Coshak to estimate the cohort size and apply base period ER's on this stock using the current ISBM equations (Sharma 2005). However, due to incomplete broods, some stability problems remain using this technique.

2.2 METHODS USED IN PREDICTING TAG RECOVERIES

Becasue I had count data, I used the Poisson model in R software package with the log-link function to test age, effort, survival and age-survival, age-effort interactions and dynamics.

The general structure for any one fishery or groups of fisheries is given by the equations below:

$$\mu_{t,f,a} = \exp\left(\beta_0 + \sum_{i=1}^{3}\beta_i : (a) + \sum_{f=1}^{n}\beta_f\,(S_{t-a}) : a + \sum_{f=n+1}^{2n}\beta_f\,(R_{t-a}) : (a) + \sum_{f=2n+1}^{3n}\beta_f\,(E_t) : (a) + \varepsilon\right) \quad (2.1)$$

$$LP = \beta_0 + \sum_{i=1}^{3}\beta_i : (a) + \sum_{f=1}^{n}\beta_f\,(S_{t-a}) : a + \sum_{f=n+1}^{2n}\beta_f\,(R_{t-a}) : (a) + \sum_{f=2n+1}^{3n}\beta_f\,(E_t) : (a) + \varepsilon \quad (2.2)$$

where LP is the Linear Predictor, a is the age of recovery in a particular fishery or group of fisheries, S is the survival of the Brood year associated with that age of recovery, R is the release associated with that Brood, E is the effort in the year that the fishery was observed (for simplification purposes we use a catch-index in pre-terminal ocean fisheries), and the Y_i's (i.e. the number of recoveries observed b age in a fishery) are distributed **Poisson (μ).** These methods are similar to those used by Cormack and Skalski (1992).

Under the null:

$H_0: \beta_1 = \beta_2 = \beta_3 = \ldots\ldots \beta_n = 0$

Under $H_A: \beta_1 \neq 0$ and/or $\beta_2 \neq 0$ and/or $\beta_3 \neq 0$……..and/or $\beta_n \neq 0$

2.2.3 Data Used

To illustrate the use of this technique, I used Upriver Bright data across stocks and ages and stratified recoveries by age for the various groups of fisheries, namely Canadian ISBM fisheries, US pre-terminal ISBM fisheries, US-terminal ISBM fisheries, escapement and other recoveries. So, in this case n=5 fisheries and the parameter values estimated would be a function of the age and fishery specific values in each fishery or escapement. **One should note that this method will not be entirely analogous to the current ISBM index as that also includes incidental mortalities which are a function of the proportion non-vulnerable (PNV) in each of the fisheries. This formulation will not account for fishery specific changes due to differences in the PNV's as this is aggregated across a number of fisheries, and is based only on numbers of tags (landed catch) estimates. However, this approach could easily be adapted to a total mortality based approach by making the dependent variable total mortality by age and fishery rather than landed catch.**

I generated estimates of recoveries in all these categories as all fisheries and escapement recoveries are needed to generate a cohort analysis for a particular year. I tested this approach for a few years using a hind-casting approach, to determine what would be expected in each of the years 2003 and 2004, and compared this with the number of tags observed from the CWT database and the current index. In addition, I discuss the possibility of using another index which is based on the modeled tags and observed tags in the base period only.

The data were based on estimated recoveries for the Priest Rapids tag group directly from the Exploitation Rate Analysis (ERA) in 2006 (TC Chinook *in progress*).

2.4 RESULTS

Results from each fishery are shown below (Table 2.1). Each age is significantly different from the other ages, and varies as function of the fishery, effort, release number and survival over time. Residual diagnostics for each of the final models by area are also shown inAppendix 2. Although some data points appear to be outliers, the model has a high goodness of fit overall. ANOVA's indicating the important predictor variables for each fishery are shown in Table 2.1. As stated above all variables are strongly significant for recoveries by age, over all fisheries.

Table 2.1: ANOVA’s for fishery specific recoveries as a function of effort, releases and survival

Escapement

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	96	14135.6			
a	3	3176.6	93	10959	0
a:E_t	4	711.9	89	10247.1	9.29E-153
a:R_{t-a}	4	1752.9	85	8494.2	0
a:S_{t-a}	4	4557.7	81	3936.5	0

US TerminalCatch

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	94	22661.9			
a	3	7459.1	91	15202.9	0.00E+00
a:E_t	4	1316.8	87	13886.1	7.54E-284
a:R_{t-a}	4	1971.7	83	11914.4	0
a:S_{t-a}	4	7938.2	79	3976.2	0

US Pre-terminal Catch

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	102	2098.66			
a	3	558.63	99	1540.03	9.34E-121
a:E_t	4	394.7	95	1145.33	3.89E-84
a:R_{t-a}	4	282.95	91	862.38	5.16E-60
a:S_{t-a}	4	371.92	87	490.47	3.25E-79

Canadian Fisheries

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	99	5258.9			
a	3	615.9	96	4643	3.60E-133
a:E_t	4	2861.8	92	1781.2	0
a:R_{t-a}	4	677.4	88	1103.8	2.75E-145
a:S_{t-a}	4	466.9	84	636.9	9.60E-100

Other Fisheries

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)
NULL	97	31990			
a	3	11156	94	20834	0
a:E_t	4	7879	90	12954	0
a:R_{t-a}	4	4994	86	7961	0
a:S_{t-a}	4	5329	82	2632	0

Based on the above tables, I used predictive models for each of the fisheries as shown by the equations 3 through 6 below. Each equation is a function of the fishery and has an intercept and an interaction b y age. I show the set of equations used for one set of fisheries (Escapement) below. Parameter values are taken directly from the best model fit and are shown in Appendix 2 (Table 2.1 under Escapement):

For age 2, 3 4 and 5 the equations are respectively:

$$\mu_{t,2} = \exp\left(2.09 + 50.21(S_{t-a}) + 1.41E - 16(R_{t-a}) + 0.00167(E_t)\right) \tag{2.3}$$

$$\mu_{t,3} = \exp\left(4.13 + 27.39(S_{t-a}) + 2.69E - 06(R_{t-a}) - 0.014(E_t)\right) \tag{2.4}$$

$$\mu_{t,4} = \exp\left(4.29 + 22.58(S_{t-a}) + 3.07E - 06(R_{t-a}) - 0.007(E_t)\right) \tag{2.5}$$

$$\mu_{t,3} = \exp\left(3.47 + 229.26(S_{t-a}) + 1.58E - 06(R_{t-a}) - 0.014(E_t)\right) \tag{2.6}$$

Parameter estimates for each of the model fits are also provided in Appendix 2 (Table A.2.1-A.2.1.5). These are the equations that could be used to forecast some returns. So, for a given age, release size and year, the expected returns could be predicted based on the model shown above for a particular fishery. As a result of these equations and the correlated variables, we can then determine a figure as shown below (Figure 2.1). Other figures are included in Appendix 2 for each of the fisheries.

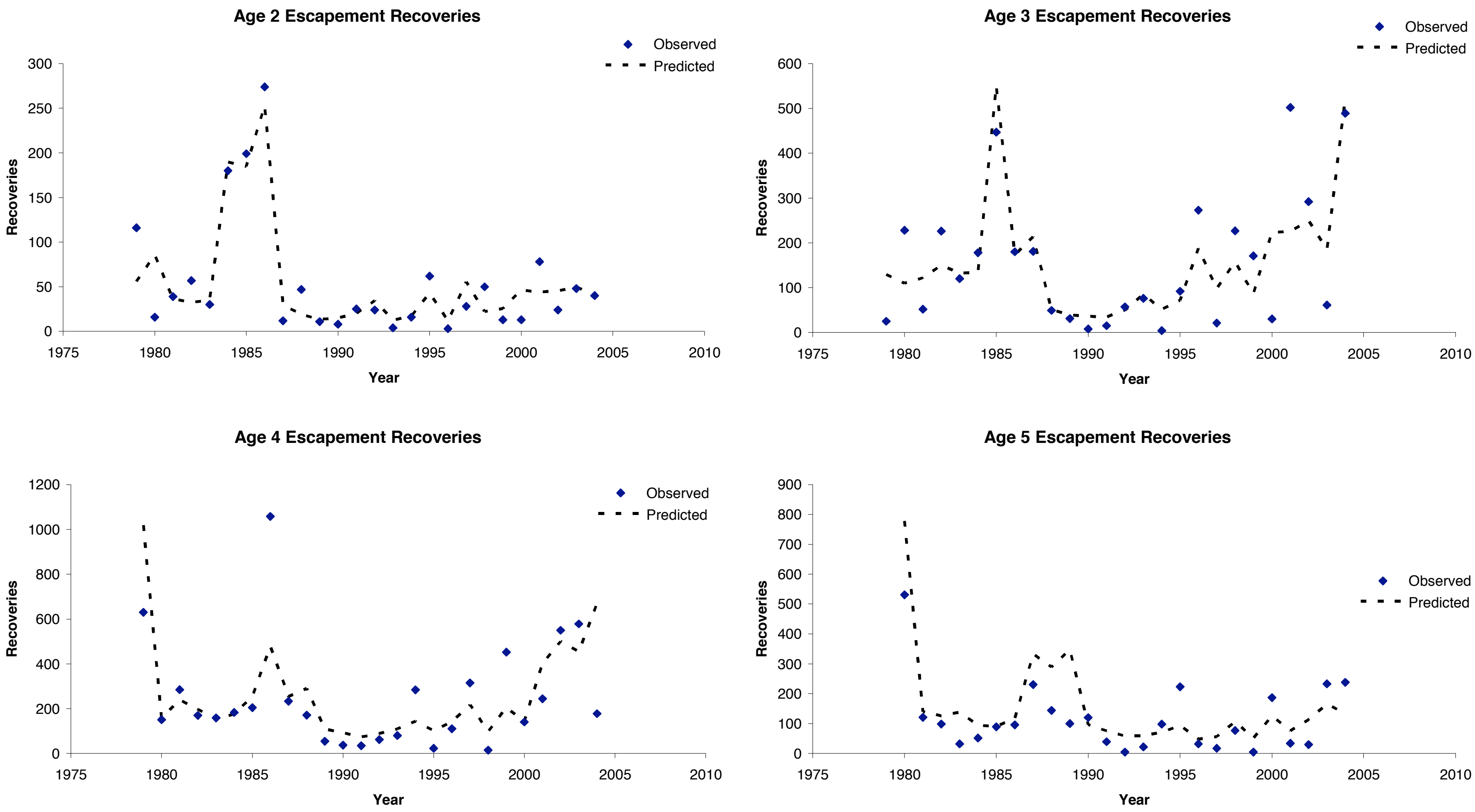


Figure 2.1 Using equations 2.3-2.6 predicting versus observed recoveries for Escapement

Based on these predictions and ISBM equations, (but now lumping the data across fisheries and only basing it on observed CWT's), data until 2002 are used to predict 2003 and 2004, and then compared to what actually happened in 2003 and 2004. Tables 2.2 and 2.3 look at predicted versus estimated current ISBM index using equations 2.7 and 2.8 for the US and Canadian fisheries respectively.

$$ISBMIdx_{s,y} = \frac{\sum_{i=1}^{F}\sum_{a=2}^{5}(Catch_{s,i,a,y} * AEQ_{s,i,a,y})}{\sum_{i=1}^{F}\sum_{a=2}^{5}(BPER_{i,a} * Cohort_{s,i,a,y})} \qquad (2.7)$$

where:

i) ISBM is the Individual stock based Management Index for stock s, a is age, y is year and i is the fishery of concerns effecting the stock.
ii) The AEQ stands for Adult Equivalence for stock s at age a, and fishery i at time y, and
iii) the Cohort is the cohort size for stock s, by age and fishery after natural mortality has occurred at that age.
iv) catch is in terms of estimated CWT's recovered by age.

$$BPER_{s,i,a} = \frac{\sum_{y=79}^{82}\frac{(Catch_{s,i,a,y}) * AEQ_{s,i,a,y}}{Cohort_{s,i,a,y}}}{4} \qquad (2.8)$$

where BPER is the Base Period Exploitation Rates are the average exploitation rate for stock s and fishery i in AEQ terms.

Table 2.2: ISBM Index for Upriver Bright stock in US fisheries using predicted tags

Calendar Year	ISBM actual	ISBM model	difference	bias
1983	0.58	1.22	2.13	1.13
1984	1.36	1.45	1.07	0.07
1985	2.14	1.72	0.80	(0.20)
1986	1.88	2.12	1.13	0.13
1987	2.68	2.23	0.83	(0.17)
1988	2.79	2.21	0.79	(0.21)
1989	3.15	2.08	0.66	(0.34)
1990	2.88	1.89	0.66	(0.34)
1991	1.73	2.03	1.18	0.18
1992	1.20	1.71	1.43	0.43
1993	1.34	1.51	1.13	0.13
1994	1.01	1.54	1.53	0.53
1995	1.14	1.29	1.13	0.13
1996	1.23	0.99	0.81	(0.19)
1997	1.59	0.97	0.61	(0.39)
1998	1.16	1.33	1.14	0.14
1999	1.18	1.40	1.19	0.19
2000	1.79	1.19	0.66	(0.34)
2001	1.16	1.46	1.25	0.25
2002	1.39	1.51	1.09	0.09
2003	1.38	1.74	1.26	0.26
2004	1.52	1.14	0.75	(0.25)

Average Bias for enitire TS = 0.06
Average Bias for predictive mode (03-04) = 0.00

Table 2.3: ISBM Index for Upriver Bright stock in Canadian fisheries using predicted tags

Calendar Year	ISBM actual	ISBM model	difference	bias
1983	0.72	0.54	0.75	(0.25)
1984	0.62	0.76	1.23	0.23
1985	0.52	0.45	0.87	(0.13)
1986	0.40	0.37	0.92	(0.08)
1987	0.51	0.31	0.60	(0.40)
1988	0.21	0.22	1.03	0.03
1989	0.45	0.41	0.90	(0.10)
1990	0.38	0.30	0.79	(0.21)
1991	-	0.31	-	-
1992	0.30	0.31	1.03	0.03
1993	0.10	0.31	2.93	1.93
1994	0.44	0.26	0.58	(0.42)
1995	0.11	0.27	2.40	1.40
1996	0.09	0.22	2.45	1.45
1997	0.12	0.21	1.68	0.68
1998	0.09	0.24	2.76	1.76
1999	0.18	0.19	1.05	0.05
2000	0.07	0.21	3.01	2.01
2001	0.12	0.19	1.54	0.54
2002	0.19	0.23	1.20	0.20
2003	0.59	0.19	0.32	(0.68)
2004	0.08	0.05	0.65	(0.35)

Average Bias for enitire TS = 0.37
Average Bias for predictive mode (03-04) (0.52)

Graphically, the two indices track one another quite well (Figure 2.2), though in later years the Canadian index appears to miss certain events. This is probably the reason for the positive bias overall with this index which is magnified in later years (especially 2003 where a lot more tags were recovered than predicted). In both the tables and the graphs, the model number indicates a pre-season projection versus the actual number which is a post-season estimate.

Figure 2.2: Using the status quo ISBM equations, predicting CWT recoveries and re-computing an index

In addition to the status quo, an alternative method evaluated was using the actual predictive relationship from the model and using base period covariates versus current covariates to predict. This was based on the parameter estimates from equations 2.1 and 2.2 above (Table 2.1 Appendix 2). The new index is:

$$ISBM_f = \frac{\sum_{a=2}^{5} \mu_{a,f,t} \mid S_{t-a}, R_{t-a}, E_t}{\sum_{a=2}^{5} \mu_{a,f,t} \mid S_{base}, R_{base}, E_{base}} \qquad (2.9)$$

Using this equation and the parameter estimates obtained from the best model fit for a group of fisheries, we compute an ISBM for US and Canadian fisheries respectively (Table 2.4 and 2.5). The denominator in both the pre-season and post-season index is essentially going to be the average numbers observed in the base years over all ages.

Table 2.4: New ISBM Index for Upriver Bright stock in US fisheries using predicted tags

Calendar Year	US Index pre-season	US Index post-season	difference	bias
1983	0.45	0.153	2.91	1.91
1984	0.63	0.671	0.95	(0.05)
1985	1.81	2.672	0.68	(0.32)
1986	2.74	3.723	0.74	(0.26)
1987	2.40	2.886	0.83	(0.17)
1988	1.96	2.766	0.71	(0.29)
1989	0.87	1.185	0.73	(0.27)
1990	0.45	0.534	0.85	(0.15)
1991	0.42	0.143	2.97	1.97
1992	0.37	0.151	2.47	1.47
1993	0.39	0.263	1.50	0.50
1994	0.42	0.330	1.27	0.27
1995	0.29	0.223	1.29	0.29
1996	0.31	0.462	0.67	(0.33)
1997	0.31	0.687	0.45	(0.55)
1998	0.41	0.311	1.32	0.32
1999	0.50	0.731	0.68	(0.32)
2000	0.50	0.578	0.86	(0.14)
2001	1.13	0.837	1.35	0.35
2002	1.42	1.318	1.08	0.08
2003	1.67	1.104	1.52	0.52
2004	1.52	1.383	1.10	0.10

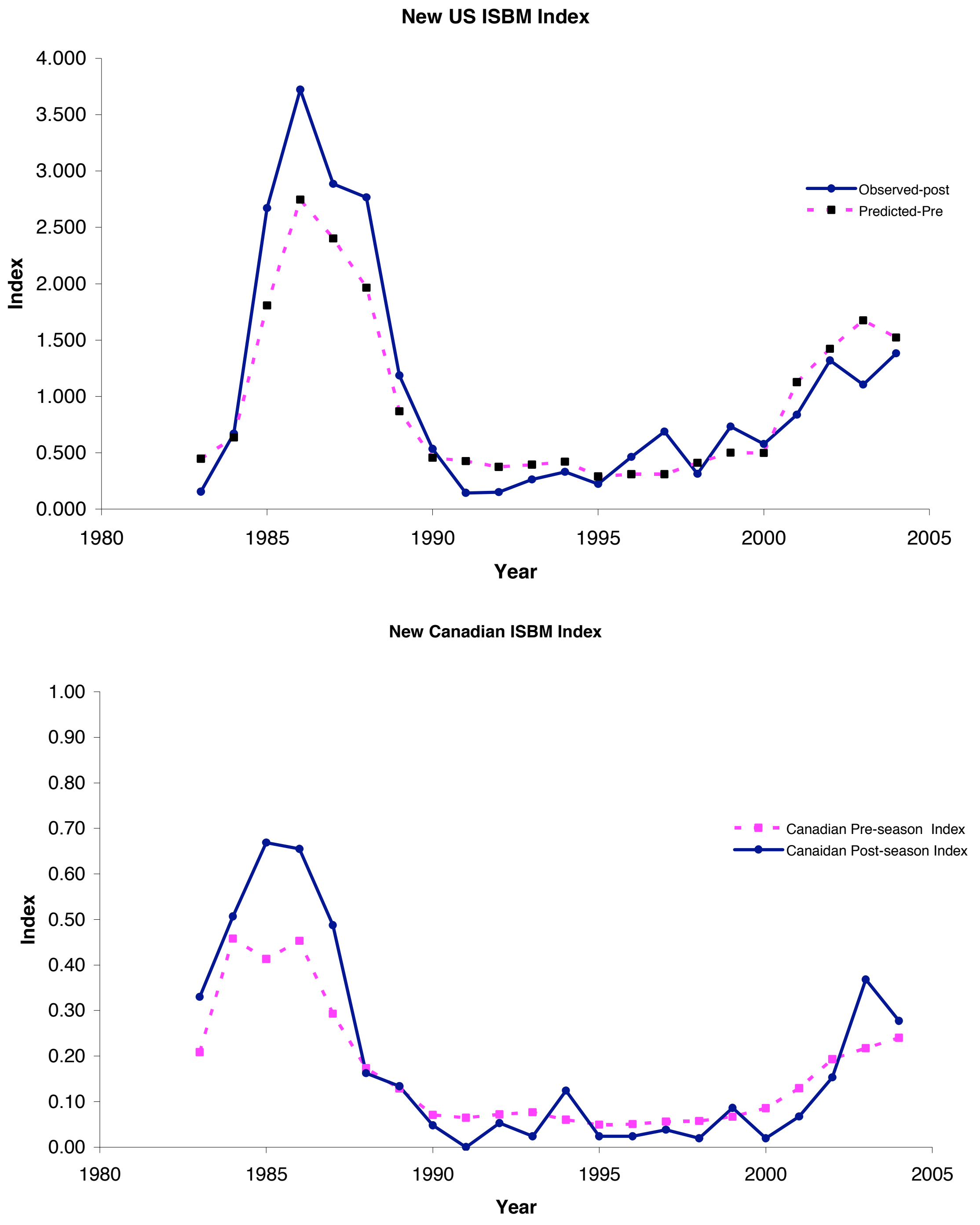
Avg Bias in 2003-2004 = 0.31
Avg Bias over entire Time series = 0.22

Table 2.5: New ISBM Index for Upriver Bright stock in Canadian fisheries using predicted tags

Calendar Year	Pre-season ISBM index	Post-season ISBM Index	Difference	Bias
1983	0.21	0.33	0.63	(0.37)
1984	0.46	0.51	0.90	(0.10)
1985	0.41	0.67	0.62	(0.38)
1986	0.45	0.65	0.69	(0.31)
1987	0.29	0.49	0.60	(0.40)
1988	0.17	0.16	1.07	0.07
1989	0.13	0.13	0.96	(0.04)
1990	0.07	0.05	1.48	0.48
1991	0.06	0.00	-	-
1992	0.07	0.05	1.37	0.37
1993	0.08	0.02	3.20	2.20
1994	0.06	0.12	0.48	(0.52)
1995	0.05	0.02	2.05	1.05
1996	0.05	0.02	2.12	1.12
1997	0.06	0.04	1.47	0.47
1998	0.06	0.02	3.01	2.01
1999	0.07	0.09	0.77	(0.23)
2000	0.09	0.02	4.46	3.46
2001	0.13	0.07	1.93	0.93
2002	0.19	0.15	1.26	0.26
2003	0.22	0.37	0.59	(0.41)
2004	0.24	0.28	0.87	(0.13)

Avg Bias in 2003-2004	=	(0.27)
Avg Bias over entire Time series	=	0.45

The two indices track one another very well (Figure 2.4). Both indices have a high correlation ($\rho>0.9$) coefficient in both cases between the pre- and post-saeason estimates. There is some year to year variation in indices over the time series. However, in general, the trend is fairly consistent over time which would indicate that for evaluative purposes, and possibly for pre-season planning, these indices would track the post-season trend fairly reliably.


New US ISBM Index

New Canadian ISBM Index

Figure 2.3: New ISBM indices based on equation 2.9 over time

2.5 DISCUSSION

Results from the above methods appear to be positively correlated and track the index post-season well with pre-season predictors. However, the use of this can only be justified from 2003 onwards as the relationship is based on the past performance. In addition, for the predictions we have some idea of the survival and effort trajectories, and if these are biased the indices will likely be biased. As such, knowledge of fishery catch rates should be known pre-season fairly precisely. Then, if we base a limit on the parameter estimates, equations 2.9 or 2.7 and 2.8 can be used to estimate the target catch for the group of fisheries to remain within a specified limit.

The method proposed using equation 2.9 is simple to calculate and transparent and will do away with the complications of the current ISBM index. On the other hand, this can only be used in cases where we have stocks represented with adequate CWTs. As Sharma (2005) indicated, there are numerous gaps in the stocks that we have in the PST (1999) treaty and stocks which have adequate coverage, and the only way to make any estimate for those stocks is to use the CTC model.

3 COMPOSITE INDICES

A lot of the problems identified with the current ISBM approach is reflective of the difficulty of projecting the index pre-season and managing to it. Another approach is to compute a composite index over groups of stock and fisheries that estimates an exploitation rate index across stocks and fisheries. Target ERI's could be determined or negotiated that would be beneficial for the stocks that are rebuilding, that are not meeting escapement targets, or that have some conservation issues. Rather than managing to these based on the ability to project fisheries, post-season evaluation would determine whether these ER targets were met for these stocks and fisheries using CWTs.

3.1 THE COMPOSITE INDEX

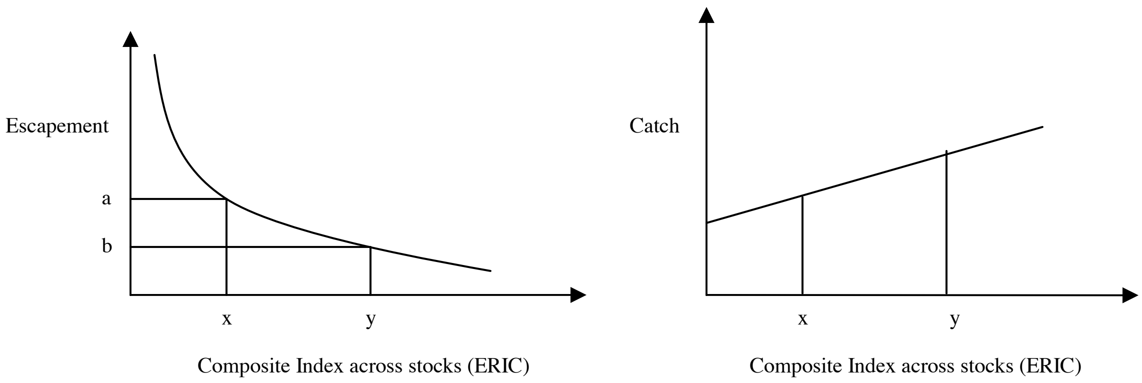


Figure 3.1: Relationship between Escapement and Composite index

3.1.1 METHODS: WHAT IS THE INDEX?

3.1.2 The Theory of the Index

Indices are commonly used in the PST process, e.g., harvest rate indexes (HRI's ; TCCHINOOK 2005). Shown here is an average composite index across stocks in a group of fisheries and the overall relationship with escapement. Hence, if a stock has an escapement goal (biologically or RER based) then the index based on a retrospective analysis might display a certain ER Index value (*x*) below which the goal is always met. If on the other hand, we observe that the corresponding index is *y* when we have a escapement of *b*, then the allowable index should not exceed a certain value (*x*) and should cause an exploitation rate reduction (y-x) in the fishery to meet goal *a* (Figure 3.1 above).

3.1.3 Computing The Index

The equation used to assess the ER Index (ERI) for a particular stock (s) is shown below:

$$ERI_{s,t} = \frac{\sum_{i=2}^{5} C_{s,i.f}}{\sum_{i=2}^{5} A_{s,i,f}} \tag{3.1}$$

where C is the catch in an ISBM fishery (by age (i)) and A is the abundance in the fishery (either terminal or pre-terminal). Since, the freshwater cohorts differ from the ocean cohort (due to presence of immature cohorts in the later), the ERI is averaged over the two fisheries to arrive at an overall ERI for that stock. For the overall ERI the CWT tag data from the following stocks were used (Table 3.1) as it relates primarily to the US ISBM indices. In addition, an overall composite for the stocks and the fishery are computed by aggregating that information over all stocks to create an Exploitation Rate Indicator Composite (ERIC, equation 3.2), where n = number of stocks.

$$ERIC_t = \frac{\sum_{s=1}^{n} ERI_{s,t}}{n} \tag{3.2}$$

Table 3.1: ERI for stocks used in the ERIC Index by year in US ISBM fisheries.

Year	Green	Lewis	Nehalem SRH	Queets	Summer	Upriver Bright	Sum Indices	ERIC
1980	0.38	0.01	0.04	0.00	0.00	0.01	0.44	0.073
1981	0.40	0.02	0.02	0.07	0.01	0.01	0.52	0.048
1982	0.35	0.05	0.06	0.16	0.00	0.00	0.61	0.055
1983	0.86	0.02	0.03	0.15	0.00	0.00	1.06	0.097
1984	0.43	0.00	0.02	0.15	0.00	0.01	0.61	0.056
1985	0.28	0.00	0.01	0.04	0.00	0.01	0.35	0.032
1986	0.18	0.01	0.05	0.29	0.00	0.01	0.54	0.049
1987	0.20	0.02	0.07	0.02	0.04	0.01	0.37	0.033
1988	0.28	0.02	0.07	0.01	0.02	0.01	0.42	0.038
1989	0.30	0.02	0.07	0.01	0.04	0.01	0.44	0.040
1990	0.63	0.03	0.12	0.01	0.03	0.01	0.83	0.076
1991	0.25	0.02	0.13	0.01	0.03	0.00	0.44	0.040
1992	0.41	0.02	0.12	0.01	0.03	0.00	0.59	0.054
1993	0.44	0.03	0.21	0.01	0.02	0.02	0.73	0.067
1994	0.31	0.00	0.16	0.01	0.00	0.00	0.47	0.043
1995	0.36	0.00	0.19	0.01	0.00	0.00	0.57	0.052
1996	0.28	0.01	0.16	0.00	0.07	0.00	0.53	0.048
1997	0.15	0.00	0.12	0.00	0.01	0.00	0.28	0.026
1998	0.18	0.00	0.12	0.00	0.01	0.00	0.32	0.029
1999	0.16	0.00	0.11	0.01	0.02	0.00	0.30	0.027
2000	0.32	0.00	0.13	0.00	0.02	0.00	0.47	0.043
2001	0.32	0.04	0.13	0.02	0.06	0.00	0.57	0.051
2002	0.10	0.03	0.13	0.00	0.05	0.02	0.33	0.030
2003	0.18	0.05	0.13	0.01	0.05	0.01	0.43	0.039

Certain criteria were used to include or exclude data. Because the primary interest is how the composite index (ERIC) behaves around or below the escapement target , points that exceed target escapement by large amounts were ignored.

3.1.3 Selection Criteria for the Index

Criteria and methodology used were:

1. ERI greater than 1.5 times average escapement target (or goal) ignored.
2. Find the index value associated with the goal being met.

3. Use an exponential relationship to set reduction in harvest rate that might cause a consequential increase in escapement.

Other possible selection criteria for ERIC

1. Greater than 1.5 time average esc (or goal) ignored.
2. Evaluate which stocks to use in the index for any particular region and then compute it either in the Fishery Indices program or directly as shown here.
3. Understand the relationship between escapement and the index around the target management parameter.
4. Use the exponential relationship to set reduction in harvest rate that might cause a consequential increase in escapement.
5. Stock abundance is forecast to be above a minimum threshold.

3.2 MODELING FUNCTIONAL RELATIONSHIPS WITH CATCH

The model describing the relationship between the index and the escapement is shown below (eq 3.3).

$$E_t = \alpha e^{-\beta(ERIC)} \qquad (3.3)$$

which can be linearized by taking log on both sides, i.e.

$$\ln(E_t) = \ln(\alpha) - \beta(ERIC) + \varepsilon \qquad (3.4)$$

In addition ERIC can be related to overall catch of a particular stock by the following expression. For simplification, I only looked at common fisheries that affected all stocks (i.e. the pre-terminal fisheries by jurisdiction) and estimated a relationship between that and overall catch:

$$ISBMCatch = \eta e^{\lambda(ERIC)} \qquad (3.5)$$

Or $\ln(ISBMCatch) = \ln(\eta) + \lambda(ERIC)$ (3.6)

And $ERIC = \dfrac{\ln\left(\dfrac{ISBMCatch}{\eta}\right)}{\lambda}$

3.3.RESULTS OF THE COMPOSITE INDEX

The ERIC- escapement relationship for some key stocks (Summers, Queets, Nehalem Upriver Brights, Skagit and Nooksack Springs), the overall index across stocks, the stock specific index, and the escapement are shown in Figure 3.2 below.

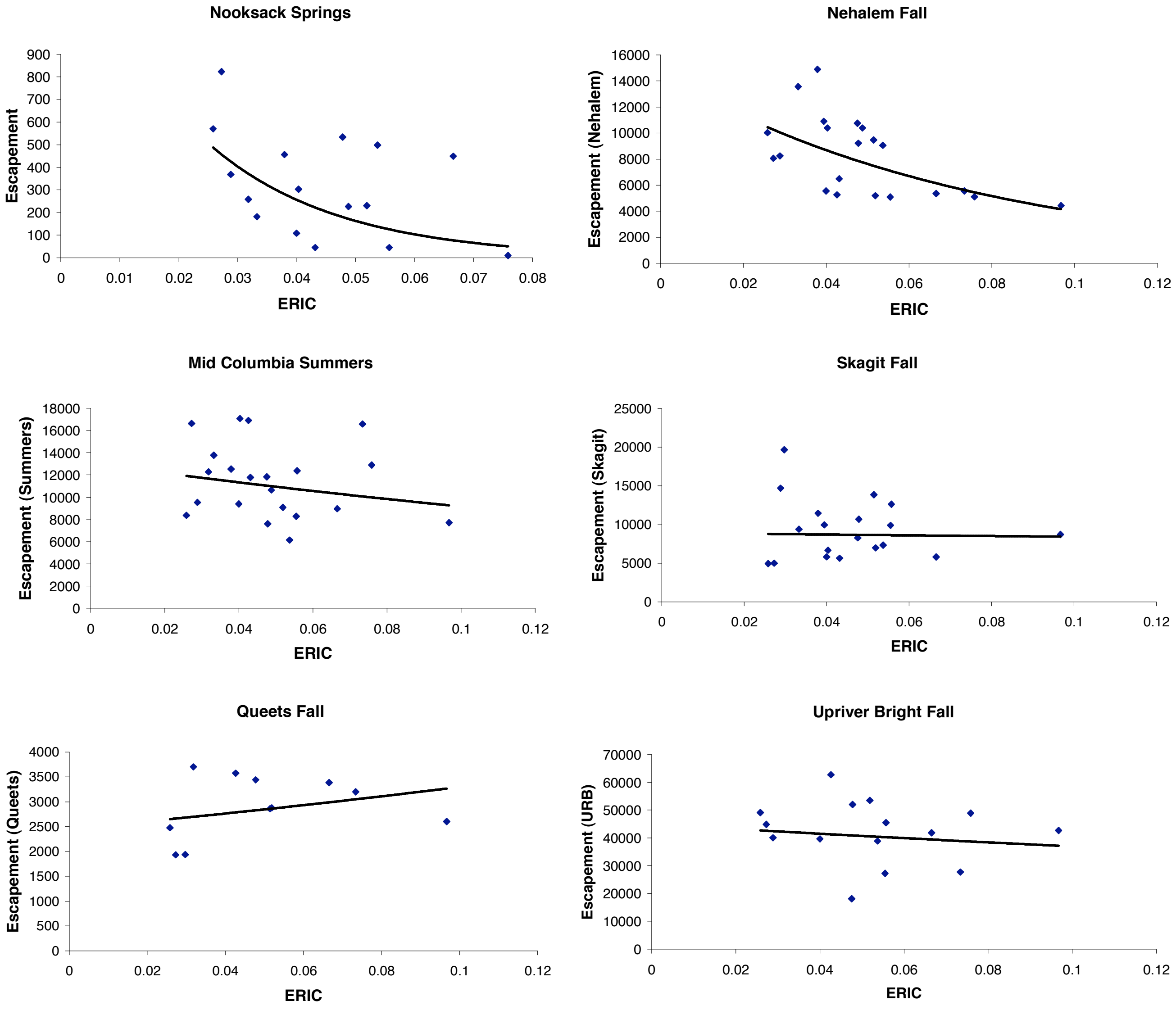


Figure 3.2: Relationship between ERIC and Escapement for 6 stocks

Most of the stocks do follow the expected relationship quite well; an exception is the Queets Fall Chinook. However, only two of the relationships are significant (Nehalem and Nooksack Springs, Table 3.2). This is probably due to a significant effect on these stocks from the mixed stock fisheries, while the other stocks (especially URBS, Summers, Queets and Skagit) are effected more by the terminal fisheries, and this composite is taking the average effect of the two fisheries.

Table3.2: ANOVA's indicating the effect of the β parameter in equation 3.4 above:

Nooksack

	df	*SS*	*MS*	*F*	*Significance F*
β	1	6.24	6.24	6.06	0.027
Residual	14	14.40	1.03		
Total	15	20.64			

Nehalem

	df	*SS*	*MS*	*F*	*Significance F*
β	1	1.03	1.03	12.02	0.003
Residual	19	1.63	0.09		
Total	20	2.67			

Mid Columbia Summers

	df	*SS*	*MS*	*F*	*Significance F*
β	1	0.08	0.08	0.92	0.35
Residual	19	1.65	0.09		
Total	20	1.73			

Skagit Fall

	df	*SS*	*MS*	*F*	*Significance F*
β	1	0.00	0.00	0.01	0.93
Residual	17	2.74	0.16		
Total	18	2.74			

Queets

	df	*SS*	*MS*	*F*	*Significance F*
β	1	0.04	0.04	0.79	0.40
Residual	9	0.48	0.05		
Total	10	0.53			

Upriver Brights

	df	*SS*	*MS*	*F*	*Significance F*
β	1	0.02	0.02	0.19	0.67
Residual	13	1.36	0.10		
Total	14	1.38			

For URBS, Skagit fall, Mid-Columbia Summers and Queets a relationship between the terminal ERI and escapement that is stock specific may be more appropriate than the overall Pre-terminal and Terminal composite.

Relationship between target catch (pre-terminal catch) and the index is also shown below (Figure 3.3). This relationship is significant (Figure 3.3, Table 3.3). The equation related to this is shown below in equation 3.7.

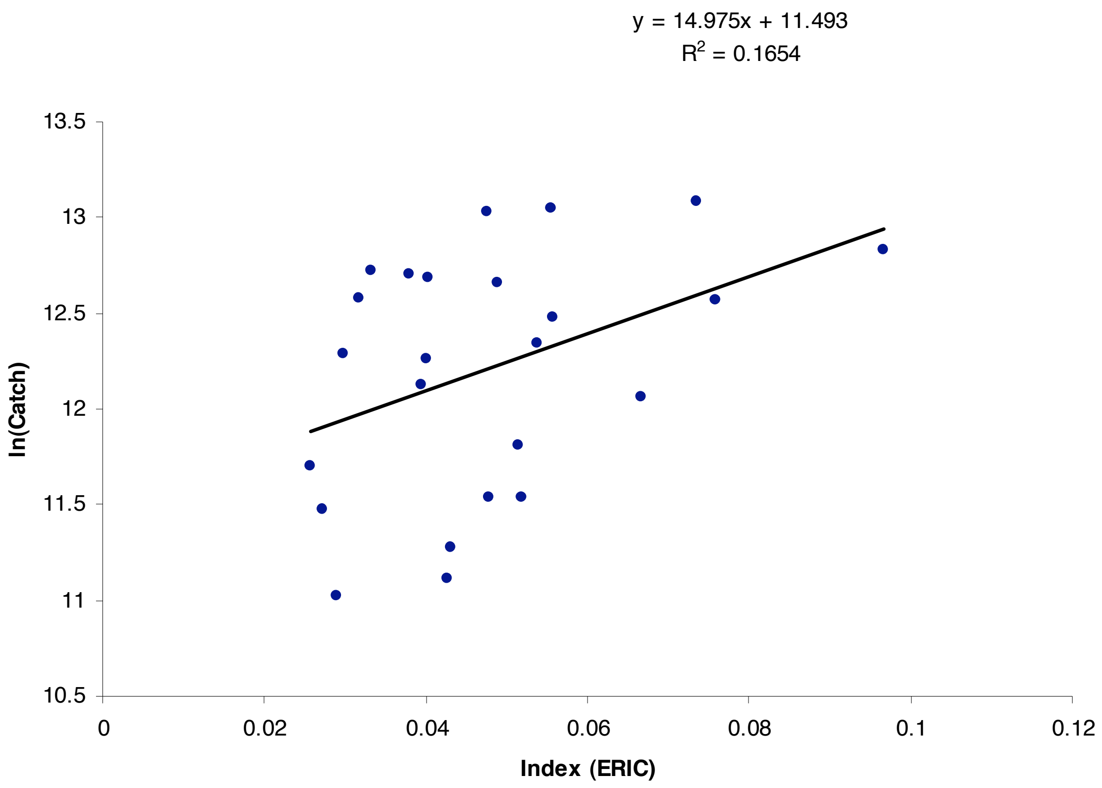


Figure 3.2: Relationship between ERIC and Catch

$$\ln(ISBMCatch) = 11.493 + 14.975(ERIC) + \varepsilon \qquad (3.7)$$

Based on the above analysis, if we choose 0.025 as a threshold value related to escapement for, say, the Nooksack and the Summers, then if these stocks are predicted to be below their escapement goal, for a certain sub group of fisheries we could reduce the sub group target catch by computing the catch quota substituting 0.025 with ERIC. In this case that roughly translates to 142,591 catch? across all the US ISBM pre-terminal fisheries. In another example, if the Upriver Brights and some other stock group are below a certain level, an overall reduction in catch to correspond to a value of 0.045 (target below which escapement goal of 40000 Chinook is not met), would give a maximum allowable catch of 192,383 is the pre-terminal ISBM fisheries.

The mechanics of this are described below:

1) Specific groups are determined to be below a certain escapement goal or lower bound.
2) A target x% in ERIC is prescribed as a value that will be beneficial for the stock groups of concern.
3) This reduction to x% means a maximum catch limit of y in the fishery or fisheries.

3.4 DISCUSSION

The provided alternative framework is somewhat like an AABM fishery though this is constrained by weak stock status of some composite group of stocks. In essence, a composite index is used to evaluate a historic relationship with escapement objectives?. This index could possibly then be used in an appropriate manner to constrain a fishery so as to meet the escapement objective. The advantages of this approach are that the Fishery Index program could be used to provide this estimate, and subsets of the index could be run and related it to catch. Thus the current infrastructure could easily be used to improve and build this technique. However, as noted, there is not a strong relationship between catch and this index, and there is only a weak relationship between the index and abundance. It would probably be wiser to look at this index as an absolute Exploitation Rate for the stock and relate it and abundance to escapement. Thereby, the relationship between the absolute ER, abundance, and escapement could be evaluated. It might also make sense to break this into Terminal and pre-terminal fisheries and assess this relationship, and thereby determine some Threshold target catch.

As far as implementation and management controls are concerned it is easy to implement as it will provide a target limit to achieve. However, the criteria by which to assess these limits is problematic, as it is subjective to some weak stock criteria which have had problems in the past. In addition to being a function of the weak stock criteria, target composite ER and catch limits would need to be assessed. Finally, the choice of stocks used in this approach will largely effect the composite so it must not be weighted too heavily for one region or we could have region specific composites, which would affect common fishery catches. This of course gets to be more complicated, and assessing compliance with some overage/underage provision gets difficult as well.

Under this approach, the pre-terminal and terminal fisheries would need to be managed separately as fisheries that encounter a common pool of stocks. Hence, the example should pertain probably only to pre-terminal fisheries and thus an index should then be evaluated across only those fisheries, and not include terminal rates as we have shown.

Finally, the current Management criteria used in the Pacific Fisheries Management Council address this in that Snake River Falls, Klamath, and other weak stocks drive overall catch, though some of the targets and thresholds may not match with the escapement targets and such. Essentially, the approach could be modified to relate this to a rebuilding target and threshold that might match the productivity of the stock in its current state. One should note, however that abundances below a certain threshold coupled with any level of ERIC will result in missing the escapement goal (e.g. summer Chinook, Snake River fall Chinook, and the Klamath in 2006). Thus, when these events occur a target reduction in catch will also need to be developed.

4 EFFORT BASED INDICES

4.1 THE CONCEPT

Effort controls in fisheries management have been used for the last few centuries (Smith 1991). As such, this is nothing new in this management approach proposed here. Baranov (1918) developed simple age structured models, and mathematically derived what the relationship between catch and population change at a particular time may be as function of harvest rate. Doubleday (1976) developed this approach to what is currently used in age structured stock assessment models universally. We take the method developed by Doubleday (1976), adapted by Fournier and Archibald (1992) and further modified by Severide and Quinn (2004) for Chinook and adapt it to the current model structure used in the cohort analysis algorithm (TCChinook 05-03). A clear distinction, however between the cohort analysis and the statistical catch at age is that the former moves backward in time while the latter moves forward in time estimating key parameters in the continuous catch equation formulation.

4.2 METHODS

Fournier and Archibald (1992) describe a statistical catch at age model. A slight modification of their approach could be used to model Chinook salmon. In essence, different components of ocean catch, and terminal catch data by stock and age in conjunction with escapement data, can be used to estimate parameters such as recruitment to age 2, fishing mortality by fisheries, stock and age, maturation and vulnerability schedules by age for fisheries. This method can be extremely useful in cases where our escapement data may not be up to data standards (e.g. some of the Puget Sound, and North Central British Columbia escapement data).

The method uses a forward projection algorithm that is based on estimation of certain key parameters in the backwards run reconstruction. The model uses an optimization function to find the parameters that minimizes the difference between model projections and observed ocean catches of the stock by age and fishery of concern (Deriso et al 1985) by maximizing the likelihood functions between observed and predicted catches in the two fisheries and escapements. The prototype model that we have developed is tuned to ocean catches, terminal catches and escapement. For the ocean component the equations are shown below:

Ocean Fisheries:

$$N_{2,t} = Recruitment \text{ estimated} \tag{4.1}$$

Recruitment to age 2 and time t is estimated as a function of the model projected catches and escapement.

$$N_{a+1,t+1} = N_{a,t}e^{-(F_{a,t}+M_a)} - N_{a,t} \times MR_{a,t} \tag{4.2}$$

Population size at time t, is a function of population size at time t-1, and is a function of both fishing mortality at that age and time, and natural mortality at that age (equation 4.2) as well as the fraction of the population that matured at the previous age (MR) and entered the terminal area.

In order to project catch, we need to estimate a catchability coefficient (q_0) as a function of effort (equation 4.3).

$$Ffull_t = q_O \times E_t \tag{4.3}$$

Fishing mortality at age is then estimated as a function of age specific vulnerability and F (full) (eq.4.4)

$$F_{a,t} = V_{a,t} \times Ffull_t \tag{4.4}$$

Catch at age and time is then projected as a function of ocean cohort at a particular age, and fishing mortality and natural mortality at that age (eq. 4.5).

$$C_{a,t} = N_{a,t} \times (1 - e^{-(F_{a,t} + M_a)}) \times \frac{F_{a,t}}{F_{a,t} + M_a} \tag{4.5}$$

Equations 4.3 to 4.5 will be repeated sequentially for groups of ISBM fisheries and other prêt-terminal ocean fisheries, followed by maturation and a terminal fishery catch

Terminal Fisheries

For terminal fisheries, we have another set of equations. They are similar to the ones used above but have the added component of estimating maturation from the ocean cohort to the terminal area.

$$N_{a,t_T} = \left(N_{a,t} - C_{a,t}\right) \times MR_{a,t} \tag{4.6}$$

where $N_{a,t\,(T)}$ is the age a abundance at time t in terminal area (T), and MR is the maturation rate at age a (time t). This is a function of the ocean cohort at time, t.

Equations similar to the ones above (eq. 4.3, 4.4 and 4.5) are used to project terminal catch (eq. 4.7, 4.8 and 4.9).

$$Ffull_{tT} = q_T \times E_{tT} \tag{4.7}$$

where the subscript T indicates terminal effort (E) and catchability (q).

$$F_{a,tT} = V_{a,t_T} Ffull_{tT} \tag{4.8}$$

where F(a,t, T) is fishery specific mortality by age and is a function of vulnerability by age.

$$C_{a,tT} = N_{a,tT} \times (1 - e^{-(F_{a,tT})}) \tag{4.9}$$

where C(a,t T) is the projected catch in the terminal area (we assume loss due to Natural Mortality is zero).

Escapement at age is then calculated using equation 4.10.

$$Esc_{a,t} = N_{a,t_T} - C_{a,t_T} \tag{4.10}$$

The Likelihood Equation used in fitting these different data sources is:

$$L(Model \mid C_{a,t,f}) = \prod_{f=1}^{n} \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left[-\frac{\left(C_{a,t,f}) - (\hat{C}_{a,t,f})\right)^2}{2\sigma^2} \right] \tag{4.11}$$

If the continuous catch equation model works then a direct Fishing mortality rate can be computed assuming catchability (q) can be estimated across all fisheries. Thus harvest can be limited based on effort and catchability (eq 4.3 and 4.7) respectively across a group of fisheries.

Using a base set of effort scalar years, projected Indices can be computed as a ratio of Effort and selectivity (vulnerability) in the different ISBM fisheries using the equation below:

$$ISBM_{f,t} = \frac{\displaystyle\sum_{f=1}^{n}\sum_{a=2}^{5} \frac{1 - e^{v_{a,t}q_{f,t}E_t}}{4}}{\displaystyle\sum_{f=1}^{n}\sum_{a=2}^{5} \frac{1 - e^{v_{a,base}q_{f,base}E_{base}}}{4}} \tag{4.12}$$

where i, is the fishery respectively.

Another index can be computed similar to equation 2.9 shown below:

$$ISBM_{f,t} = \frac{\displaystyle\sum_{a=2}^{5} \mu_{a,f,t} \mid q_{f,t}, v_{a,f,t}, E_{f,t}}{\displaystyle\sum_{a=2}^{5} \mu_{a,f,t} \mid q_{fbase}, v_{abase,fbase}, E_{fbase}} \tag{4.13}$$

where μ is the number of tags predicted by stock, age and time in an ISBM fishery, q is the catchability coefficient by fishery and time, v is the vulnerability by age, fishery and time and E is the effort by fishery and time. This of course can be used in predictive and prospective mode by evaluating what happened and what would have been predicted based on the tag projections.

Alternatively, we can move away from an index completely and look at limits on equation 4.4 and 4.7 respectively, by converting the fishing mortality directly into an exploitation rate or harvest rate in a terminal area (eq. 4.14) averaged across fisheries and summed if working on a common cohort (either terminal or pre-terminal).

$$ER_f = \sum_{f=1}^{n}\sum_{a=2}^{5} \frac{1 - e^{v_{a,t}q_{f,t}E_t}}{4} \tag{4.14}$$

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4.3 FEASIBILITY STUDY WITH UPRIVER BRIGHTS

I analyzed data on Upriver Bright populations of Chinook salmon using the effort-based approach. Data were based on the Priest Rapids Indicator tag program and stratified by different recovery areas, mapping to groups of ISBM fisheries by nation. Ie used the above described model structure to fit to this data set.

Based on these I compute the following:

i) an index that is based entirely on effort, catchability and selectivity and weighted by abundance in the pre-terminal and terminal fishery (in our case with URBS, this occurs only for the US fishery, eq 4.12 above).
ii) Use the method shown in Chapter 2 (eq 4.13) to compute an index that sums recoveries across tags.
iii) Avoid using an index altogether and compute an Exploitation rate cap that is sustainable for the stock in question.

I will demonstrate each of these in the next section.

4.3.1 Results of the model and index based on effort, selectivity and catchability

I used effort indices computed as function of data in the Ceiling file (TCChinook 05-03), and used the tag recovery data based on the 2004 ERA for Priest Rapids Upriver Bright stock. The fits over all ages and fisheries based on this model are good (Figure 4.1). The model chosen was based on trying different model structures and comparing the Akaike Information Criteria (AIC, Akaiki 1991) across these models. The final model estimated catchability and vulnerability across four fisheries by three periods (pre-1985, between 1985 and 1996, and 1997 onward to correspond to the different regimes of the Pacific Salmon Treaty). In addition the model also estimated recruitment to age 2 across each time period (28 years starting with Brood Year 1975), and maturation by years that corresponded to ocean regime shifts (pre 1987, 1987-1997, and after 1997) that corresponded to changes in ocean productivity (Beamish et. al. 2005, Hare et. al. 1999).

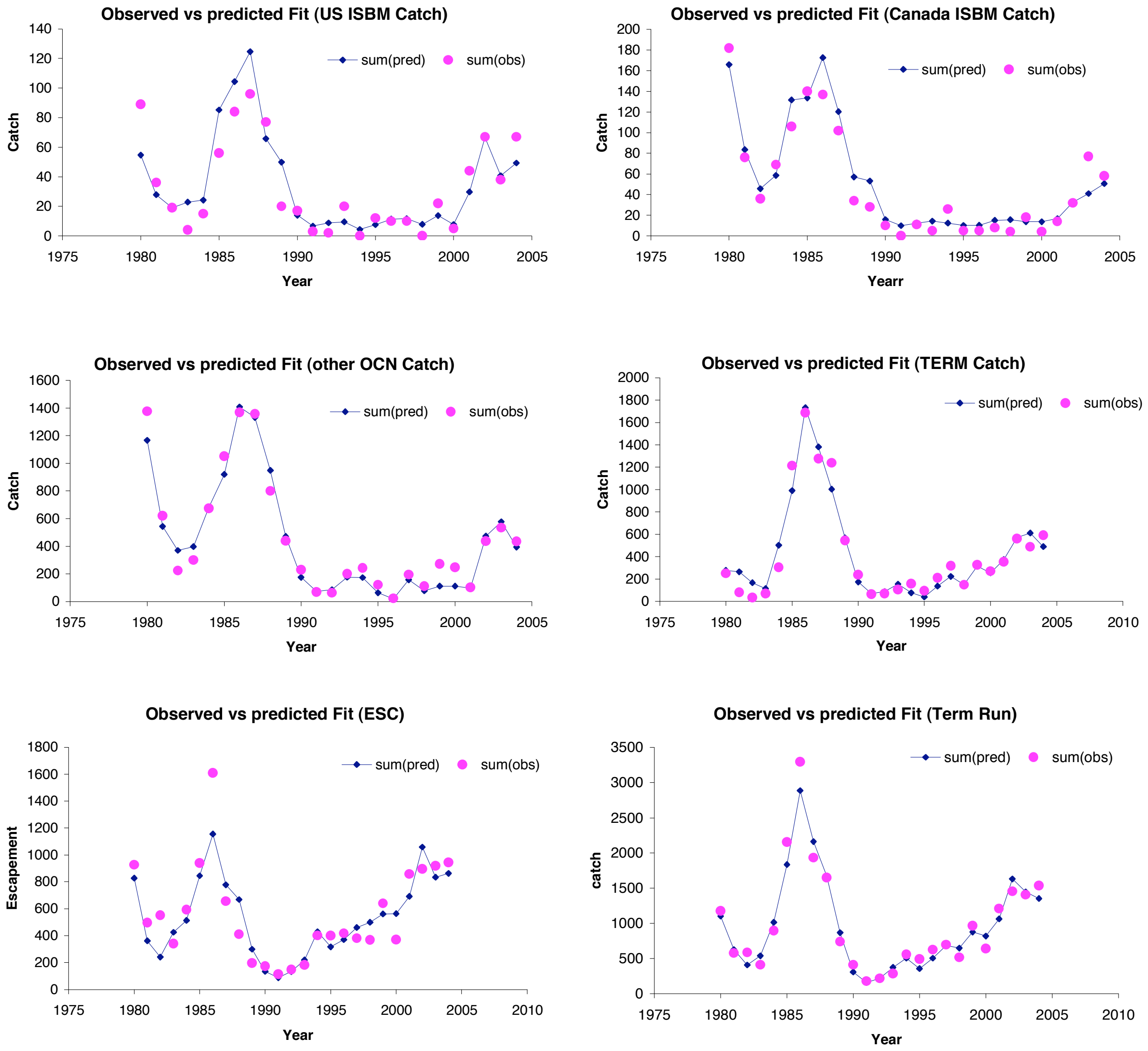


Figure 4.1: Model based fits for the different fisheries, escapement and Terminal run

Based on the fits and the residual diagnostics, the model appears to be an unbiased predictor of catch in different fisheries. Now, based on the model based estimates of catchability, vulnerability and effort, I can compute an index that is weighted by the estimated abundance if it is a function of both the terminal and pre-terminal cohort. The index computed as function of the parameter estimates obtained (Table 4.1 and Table 4.2) are shown in Figure 4.2.

Table 4.1: Vulnerability (Selectivity) parameters for the Upriver Bright stock by Fishery groups and time periods

Fishery	Time Period	Age 2	Age 3	Age 4	Age 5
US Pre-terminal ISBM	1977-1984	0.00	0.50	1.00	1.00
US Pre-terminal ISBM	1985-1994	0.03	0.13	0.20	1.00
US Pre-terminal ISBM	1996-2002	0.01	0.57	1.00	1.00
US terminal ISBM	1977-1984	0.24	0.48	1.00	1.00
US terminal ISBM	1985-1994	0.02	1.00	0.91	1.00
US terminal ISBM	1996-2002	0.50	0.74	0.99	1.00
Canaidan ISBM	1977-1984	0.05	0.36	1.00	1.00
Canaidan ISBM	1985-1994	0.04	0.09	0.24	1.00
Canaidan ISBM	1996-2002	0.00	0.07	0.21	1.00
Other fisheries	1977-1984	0.00	0.14	0.66	1.00
Other fisheries	1985-1994	0.00	0.11	0.47	1.00
Other fisheries	1996-2002	0.00	0.03	0.50	1.00

Table 4.2: Catchability (q) parameters for the Upriver Bright stock by Fishery groups (namely pre-terminal US and Canadian ISBM, terminal US ISBM and other Ocean (OCN)) and time periods

Fishery	1977-1984	1985-1994	1996-2002
q_US Pre-Terminal ISBM	0.020	0.084	0.036
q_US Terminal ISBM	0.019	0.013	0.010
q_Canada ISBM	0.060	0.142	0.259
q_other ocn	0.670	0.606	0.625

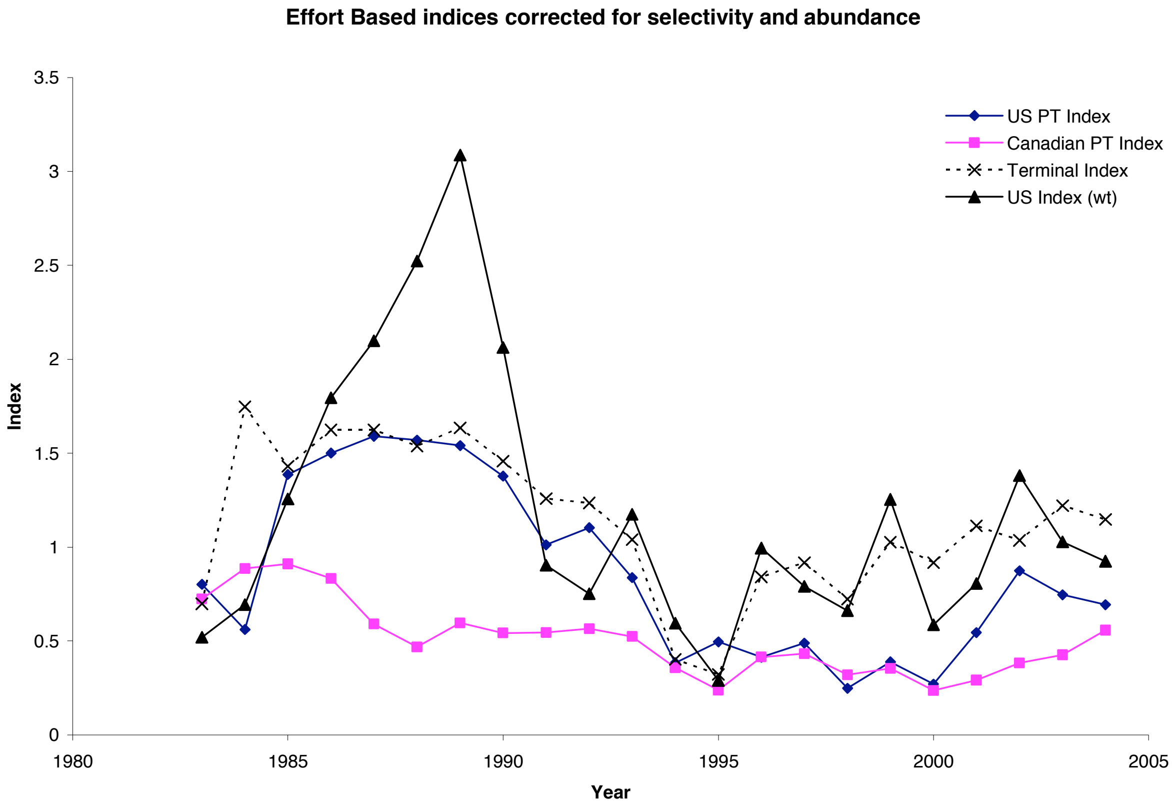


Figure 4.2: Effort, selectivity and catchability based indices

Alternatively, the age structured model could be used to project tags and evaluate what we observe relative to the base period to create an index. This is shown below (Table 4.3 and Table .4) for the US and Canadian fisheries respectively:

Table 4.3: Comparing indices based on the catch at age model and observed tags for US fisheries

Calendar Year	US Index pre-season	US Index post-season	difference	bias
1983	0.29	0.15	1.87	0.87
1984	1.11	0.67	1.65	0.65
1985	2.26	2.67	0.85	(0.15)
1986	3.86	3.72	1.04	0.04
1987	3.17	2.89	1.10	0.10
1988	2.25	2.77	0.81	(0.19)
1989	1.30	1.19	1.09	0.09
1990	0.39	0.53	0.74	(0.26)
1991	0.16	0.14	1.12	0.12
1992	0.20	0.15	1.34	0.34
1993	0.34	0.26	1.31	0.31
1994	0.17	0.33	0.52	(0.48)
1995	0.10	0.22	0.45	(0.55)
1996	0.31	0.46	0.67	(0.33)
1997	0.49	0.69	0.72	(0.28)
1998	0.33	0.31	1.06	0.06
1999	0.69	0.73	0.94	(0.06)
2000	0.55	0.58	0.96	(0.04)
2001	0.85	0.84	1.01	0.01
2002	1.34	1.32	1.02	0.02
2003	1.37	1.10	1.24	0.24
2004	1.13	1.38	0.82	(0.18)

Table 4.4: Comparing indices based on the catch at age model and observed tags for Canadian fisheries

Calendar Year	Pre-season ISBM index	Post-season ISBM Index	Difference	Bias
1983	0.28	0.33	0.85	(0.15)
1984	0.63	0.51	1.24	0.24
1985	0.64	0.67	0.96	(0.04)
1986	0.83	0.65	1.26	0.26
1987	0.58	0.49	1.18	0.18
1988	0.27	0.16	1.68	0.68
1989	0.25	0.13	1.90	0.90
1990	0.08	0.05	1.58	0.58
1991	0.05	0.00	-	-
1992	0.06	0.05	1.12	0.12
1993	0.07	0.02	2.86	1.86
1994	0.06	0.12	0.48	(0.52)
1995	0.05	0.02	2.01	1.01
1996	0.05	0.02	2.04	1.04
1997	0.07	0.04	1.89	0.89
1998	0.08	0.02	3.93	2.93
1999	0.07	0.09	0.76	(0.24)
2000	0.07	0.02	3.45	2.45
2001	0.08	0.07	1.18	0.18
2002	0.16	0.15	1.02	0.02
2003	0.20	0.37	0.53	(0.47)
2004	0.24	0.28	0.87	(0.13)

The model based on tag projections and the SCAA techniques work well for the US fisheries (bias is 1%), but on a year to year basis it is biased for the Canadian fisheries (56%) for the entire time series. However, the index tracks well with both fisheries pre and post-season ($\rho>0.9$ in both cases). Probable reasons for this discrepancy are the fact that I am estimating catchability and vulnerability for time periods where fishery structure changes are known toi have been quite dramatic for Canada, and are less varied for US ISBM fisheries. Regardless, the trends are good in each case (Figure 4.3).

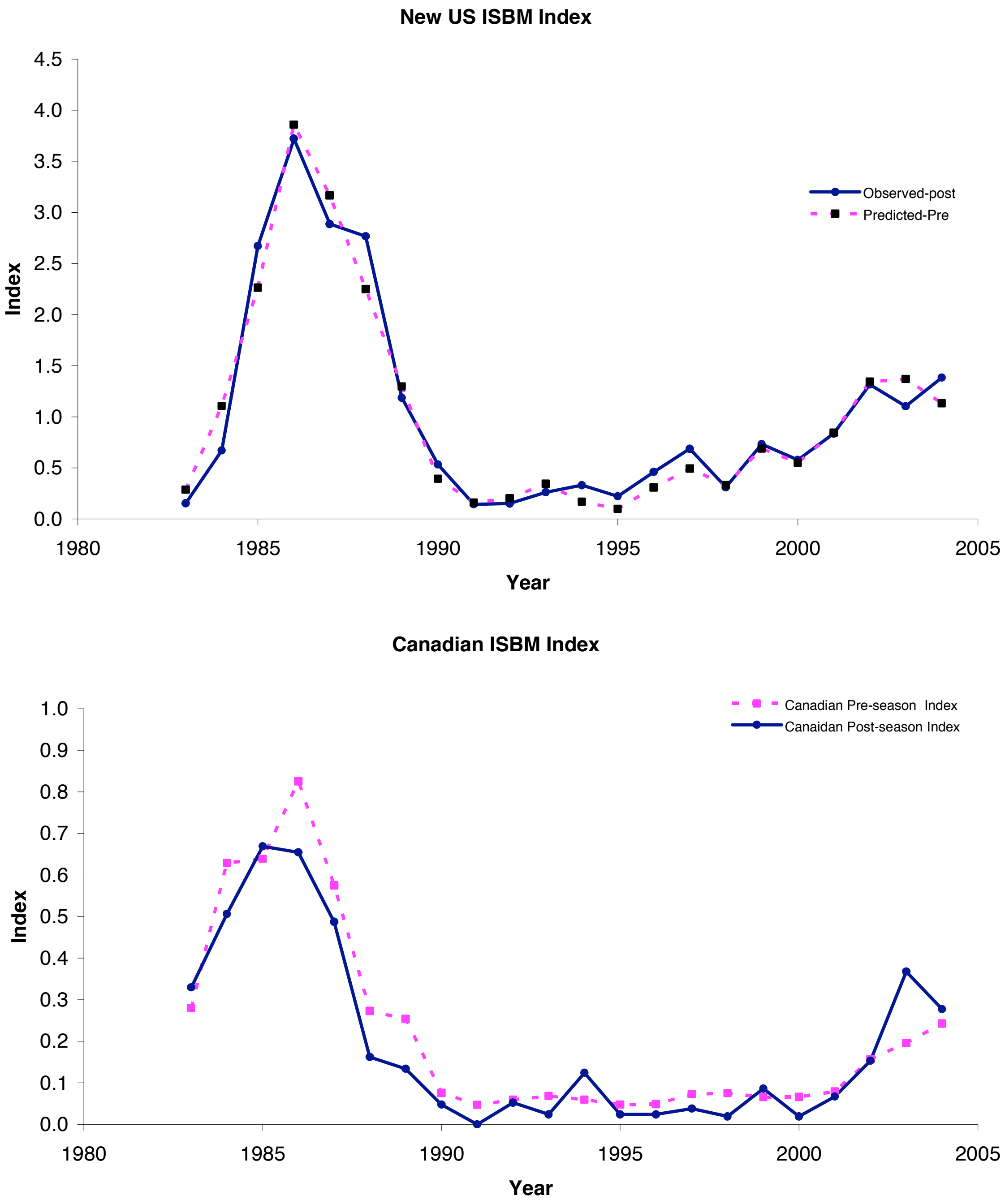
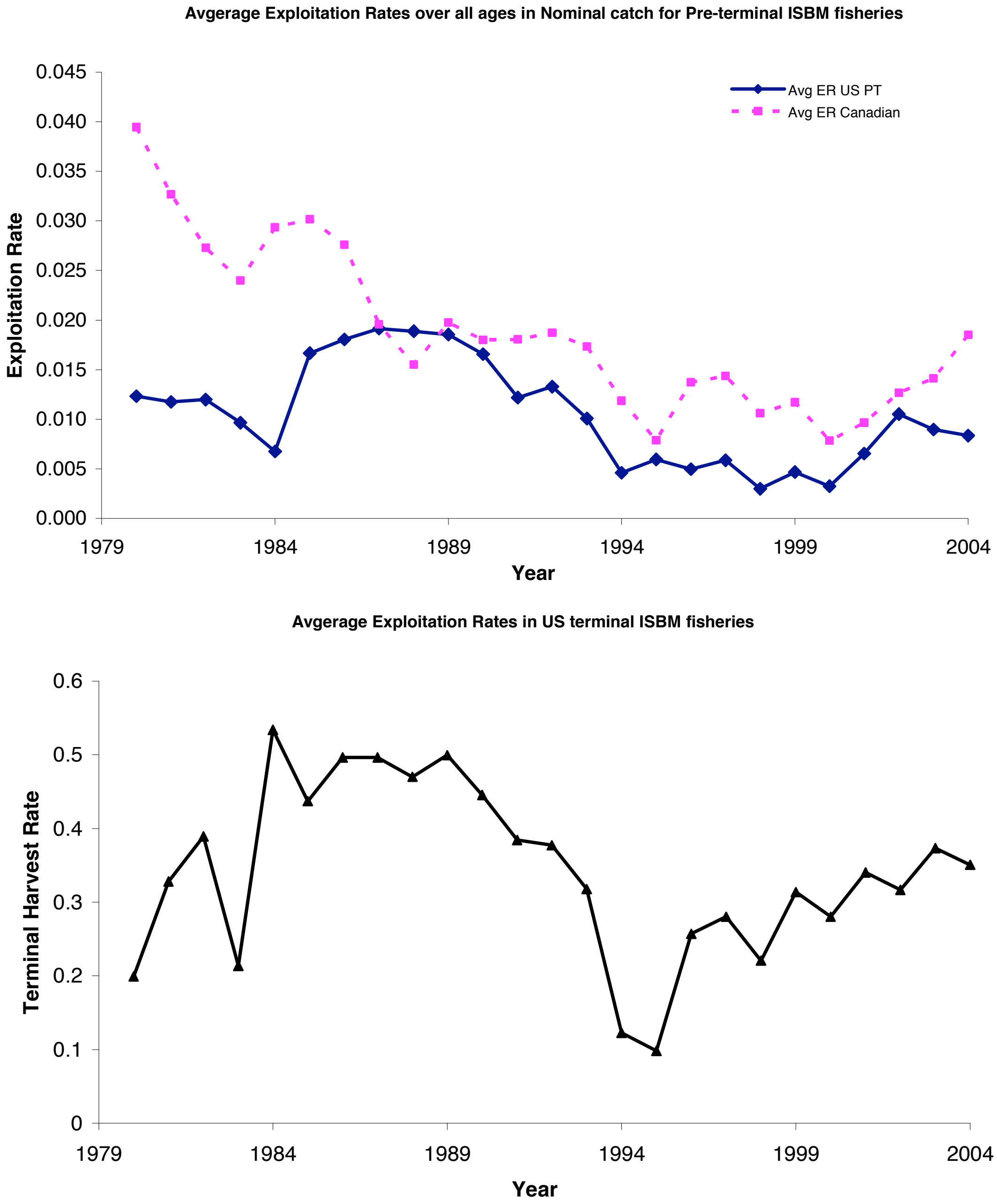


Figure 4.3: Indices computed based on equations 4.13 for US and Canadian ISBM fisheries

Finally, the approach presented here moves away from an index and the base period relationship altogether as direct measures of exploitation can be computed by a particular fishery or group of fisheries, and thus move to an exploitation rate based approach to management. The continuous equation are translated into an ER (or HR if in terminal area) by using the equation (4.14, Figure 4.4), and could then be averaged across all ages to give us a direct measure of exploitation.


Avgerage Exploitation Rates over all ages in Nominal catch for Pre-terminal ISBM fisheries

Avgerage Exploitation Rates in US terminal ISBM fisheries

Figure 4.4: Exploitation rate and harvest rate on Upriver Brights over all ages and years.

The figure illustrates the variation in exploitation and harvest rates over time. Ocean and terminal fisheries have drastically cut back harvest on this stock (due to limitations on Snake River fall Chinook which have similar run-timings), though in recent years seem to be climbing back up. One should note that the absolute number of fish caught will be a lot higher in ocean fisheries even though the exploitation rate is so low because they are fishing on a larger abundance (or available cohort).

4.4 DISCUSSION OF THE CATCH AT AGE BASED APPROACH

The design proposed here is quite different from the current approach and is based on effort indices which need to be measured accurately. The approach here is demonstrated with landed catch but could be based on either landed or total mortality. In addition, the index could also take into account AEQ's over fisheries and gear types if required. As noted in Sharma (2005), however, AEQ's are one of the reason for the instability in this index as AEQ's are only known completely when all returns of a Brood are complete.

One of the biggest advantages of this approach is that it can compute an exploitation rate by age, which is important given the current Endangered Species Act (ESA) constraints. If a weak stock based management approach is implemented, this would be extremely advantageous and fisheries or groups of fisheries could be limited to some target exploitation rates, and evaluated with tags post-season. In addition, using this approach moves away from a base period and moves into a realm of absolute rates rather than an index scaled to an arbitrary base period.

5 CONCLUSIONS

The original intent of the ISBM provision was to ensure that terminal areas meet the escapement goals of the various stocks in question. In 1999 as a way to measure that these goals were met for a stock, the pass through index was the tool agreed upon to evaluate compliance. Sharma (2005), through analysis of the pre- and post-season indices, demonstrated that these indices do not track one another and attributed other problems with the index: the pre and post-season indices do not get evaluated until two years after the fact; coded-wire tag data are limited in coverage and various stocks had no tag data to evaluate the index post-season; base period data coverage was extremely poor; and the index was unstable due to the fact that data are incomplete for some broods.

Despite all these problems, the report (Sharma 2005) demonstrated to a large extent that the exploitation in pre-terminal ISBM and terminal ISBM fisheries has substantially dropped from the historic base period harvest rates. Given that, and the inability to manage these stocks with an index pre-season, a possible solution is to track escapement on an annual basis..

The only true measure of evaluating compliance currently is with CWTs. This report demonstrates through a simplified fishery model alternative indices to measure harvest impacts. However, problems identified in Sharma (2005) will still remain if we use a base period and associated tag recoveries as numerous stocks have poor CWT data and/or poor base period CWT coverage. A solution to these problems is to move away to a more relevant base period as numerous tagging programs began after 1980.

I compared the post-season index across the gamut of methods to assess how the index has behaved as a function of the method (Table 5.1 & Table 5.2, Figure 5.1).

Table 5.1: US ISBM Indices using alternative methods

Calendar Year	Status Quo Method 1(a) corrected pre-pseason	Status Quo Method 1(a) corrected post-pseason	Method 1(b): CWT effort projection Index (pre)	Method 1(b): CWT effort projection Index (post)	SCAA Method 3(a): Effort Index	Method 3(b): SCAA CWT effort projection Index (pre)	Method 3(b): CWT effort projection Index (post)	SCAA Method 3 (c): ERA in US PT ISBM fishery	SCAA Method 3 (c): ERA in US terminal ISBM fishery
1983	1.22	0.58	0.45	0.15	0.52	0.29	0.15	0.01	0.21
1984	1.45	1.36	0.63	0.67	0.69	1.11	0.67	0.01	0.53
1985	1.72	2.14	1.81	2.67	1.26	2.26	2.67	0.02	0.44
1986	2.12	1.88	2.74	3.72	1.80	3.86	3.72	0.02	0.50
1987	2.23	2.68	2.40	2.89	2.10	3.17	2.89	0.02	0.50
1988	2.21	2.79	1.96	2.77	2.52	2.25	2.77	0.02	0.47
1989	2.08	3.15	0.87	1.19	3.09	1.30	1.19	0.02	0.50
1990	1.89	2.88	0.45	0.53	2.06	0.39	0.53	0.02	0.45
1991	2.03	1.73	0.42	0.14	0.90	0.16	0.14	0.01	0.38
1992	1.71	1.20	0.37	0.15	0.75	0.20	0.15	0.01	0.38
1993	1.51	1.34	0.39	0.26	1.17	0.34	0.26	0.01	0.32
1994	1.54	1.01	0.42	0.33	0.60	0.17	0.33	0.00	0.12
1995	1.29	1.14	0.29	0.22	0.29	0.10	0.22	0.01	0.10
1996	0.99	1.23	0.31	0.46	0.99	0.31	0.46	0.00	0.26
1997	0.97	1.59	0.31	0.69	0.79	0.49	0.69	0.01	0.28
1998	1.33	1.16	0.41	0.31	0.66	0.33	0.31	0.00	0.22
1999	1.40	1.18	0.50	0.73	1.25	0.69	0.73	0.00	0.31
2000	1.19	1.79	0.50	0.58	0.59	0.55	0.58	0.00	0.28
2001	1.46	1.16	1.13	0.84	0.81	0.85	0.84	0.01	0.34
2002	1.51	1.39	1.42	1.32	1.38	1.34	1.32	0.01	0.32
2003	1.74	1.38	1.67	1.10	1.03	1.37	1.10	0.01	0.37
2004	1.14	1.52	1.52	1.38	0.92	1.13	1.38	0.01	0.35

Table 5.2: Canadian ISBM Indices using alternative methods

Calendar Year	Status Quo Method 1(a) corrected pre-season	Status Quo Method 1(a) corrected	Method 1(b): CWT effort projection Index (pre)	Method 1(b): CWT effort projection Index (post)	SCAA Method 3(a): Effort Index	Method 3(b): SCAA CWT effort projection Index (pre)	Method 3(b): CWT effort projection Index (post)	SCAA Method 3 (c): ERA in Canadian ISBM fishery
1983	0.54	0.58	0.21	0.33	0.72	0.28	0.33	0.024
1984	0.76	1.36	0.46	0.51	0.89	0.63	0.51	0.029
1985	0.45	2.14	0.41	0.67	0.91	0.64	0.67	0.030
1986	0.37	1.88	0.45	0.65	0.83	0.83	0.65	0.028
1987	0.31	2.68	0.29	0.49	0.59	0.58	0.49	0.020
1988	0.22	2.79	0.17	0.16	0.47	0.27	0.16	0.016
1989	0.41	3.15	0.13	0.13	0.60	0.25	0.13	0.020
1990	0.30	2.88	0.07	0.05	0.54	0.08	0.05	0.018
1991	0.31	1.73	0.06	0.00	0.55	0.05	0.00	0.018
1992	0.31	1.20	0.07	0.05	0.57	0.06	0.05	0.019
1993	0.31	1.34	0.08	0.02	0.52	0.07	0.02	0.017
1994	0.26	1.01	0.06	0.12	0.36	0.06	0.12	0.012
1995	0.27	1.14	0.05	0.02	0.24	0.05	0.02	0.008
1996	0.22	1.23	0.05	0.02	0.41	0.05	0.02	0.014
1997	0.21	1.59	0.06	0.04	0.43	0.07	0.04	0.014
1998	0.24	1.16	0.06	0.02	0.32	0.08	0.02	0.011
1999	0.19	1.18	0.07	0.09	0.35	0.07	0.09	0.012
2000	0.21	1.79	0.09	0.02	0.24	0.07	0.02	0.008
2001	0.19	1.16	0.13	0.07	0.29	0.08	0.07	0.010
2002	0.23	1.39	0.19	0.15	0.38	0.16	0.15	0.013
2003	0.19	1.38	0.22	0.37	0.43	0.20	0.37	0.014
2004	0.05	1.52	0.24	0.28	0.56	0.24	0.28	0.018

The methods all show similar trends (Figure 5.1) though tracking them pre-and post season shows that certain methods, such as the corrected estimates 1(b) and 3(b), do a lot better than the current status quo (38% Sharma 2005, Appendix 1 Table 1.3). Method 1(a) (Table 2.2 and Table 2.3) has no real bias, and similarly Table 4.3 indicates relatively low bias for the catch-at-age model over the entire time period when evaluate pre- and post-season trends are evaluated.

Furthermore, if a management system is implemented which no longer relies on a base period (e.g., method 3(c)), then fisheries or groups of fisheries can be managed to exploitation rate caps if a stock is not meeting its escapement goal (Figure 4.4). Thus, effort and catchability can be used as well as gear selectivity to keep the fishery exploitation rate under a certain constraint that could be negotiated under a new agreement.

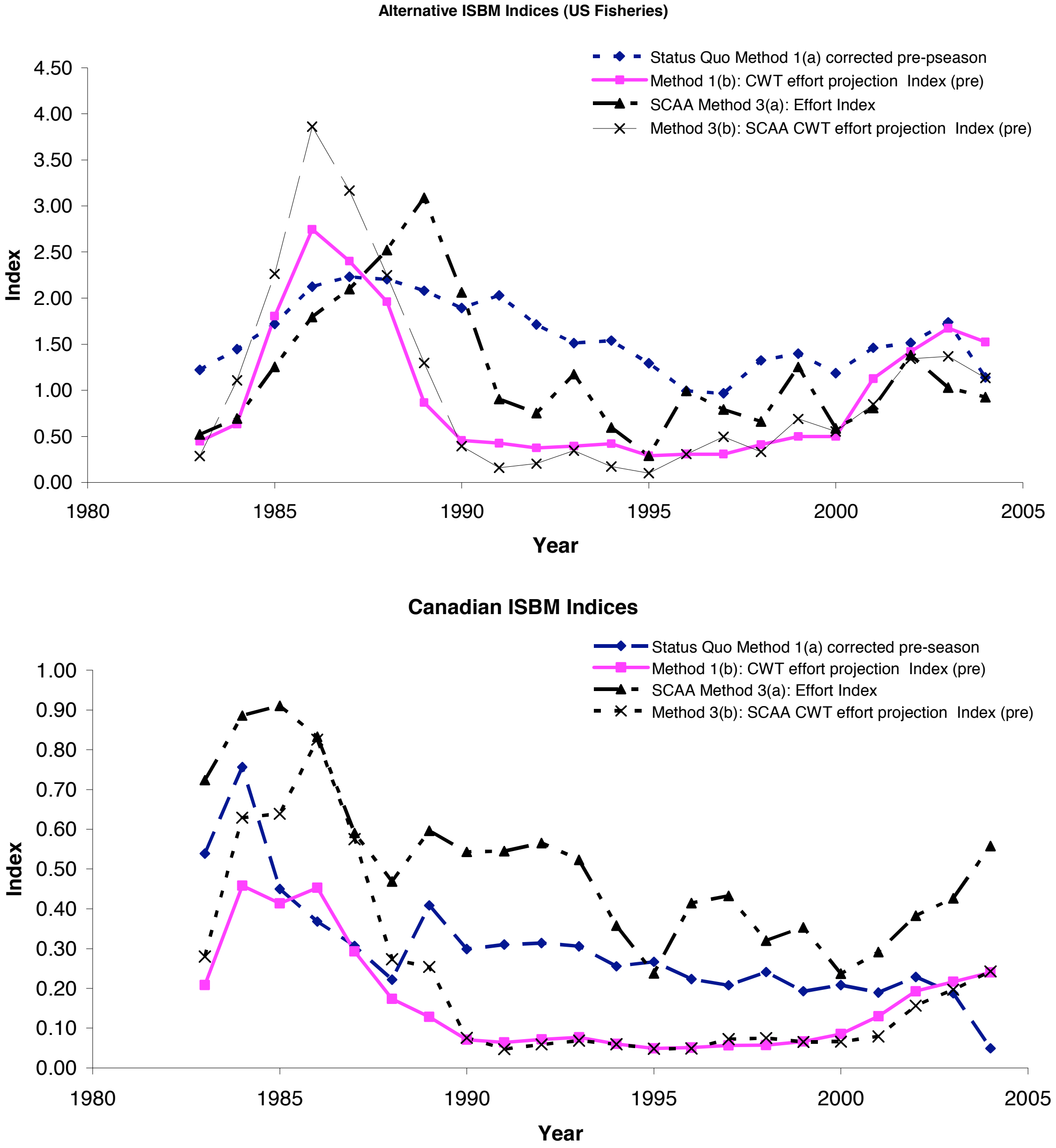


Figure 5.1: Alternative Indices for ISBM Management for Upriver Bright Chinook

Table 5.3: Comparing alternative metrics for ISBM fisheries and their performance

Problems	Method 1(a)	Method 1 (b)	Method 2 (New Harvest Rate-Catch Relationship)	Method 3 (a) SCAA (Effort Index)	Method 3 (b) SCAA	Method 3 (c) SCAA ERA based
Tracking pre and post season	Corrects	Corrects	Corrects	Corrects	Corrects	Corrects
Incomplete Brood Problems	Doesn't correct	Corrects	Corrects	Corrects	Corrects	Corrects
Data Reporting Time Line	Doesn't correct	Doesn't correct	Doesn't correct	Doesn't correct	Doesn't correct	Doesn't correct
CWT Coverage	Doesn't correct	Doesn't correct	Doesn't correct	Doesn't correct	Doesn't correct	Doesn't correct
Base period Issues	Yes	Yes	No	Yes	Yes	No
Total Mortality Capability	Yes	Yes	Yes	Yes	Yes	Yes

All methods identified still have issues with coded wire tag coverage and timelines (Table 5.1). In a pre-season methodology, method 1(b) and 3(b) are probably the best as they forecast the return and scale an index that has minimal biases and is highly correlated with an index post-season. In addition, the index using these two methods does not have the incomplete Brood stability issues.

While method 2 has merits associated with weak stock based management, it will require a completely new technical approach. Given the timeline on negotiating a new agreement, applying this index is highly unlikely. Although Method 3(c) has the same issues as Method 2 (i.e. a new way to do management) it is highly transparent, has minimal assumptions, does not rely on a base, and can actually work with exploitation rate based approaches. Because exploitation rates caps are being considered in the 2008 renegotiations, this approach and corresponding redesigning of the model may have applicability.

Finally, the purpose of the ISBM index is to insure that most stocks of concern and importance in the Pacific Salmon Treaty process are not over-fished. Since terminal and near terminal area fisheries have a direct relationship with overall stock exploitation (more so than mixed stock ocean fisheries), it may be more appropriate to track overall abundance and run size in terminal and near-terminal areas as the season progresses. Such approaches are commonly used in Bristol Bay (Hyun 2005), and could also be applied to near terminal areas as demonstrated by Hyun (2006) for the Columbia River. An extension of this approach to pre-terminal areas is the next step, and some preliminary investigative work has been conducted with this regard. The results although preliminary (Hyun personal communication) indicate that the future of these fisheries lies in using in-season management approaches with coded-wire tag indices or genetic stock based data.

If that is workable the ISBM index becomes inconsequential and should be dismissed altogether. At the very least, if the objective is track escapement, the index should be rectified to work prospectively rather than using a preseason based approach, so as to alert the salmon managers of some violations that may happen after the fisheries are prosecuted.

If in-season management is not possible, then the index should be modified to use only stocks that have tags that represent broader regions. It does appropriate for the Chinook Technical Committee or the Pacific Salmon Commission to estimate tag contributions to different stocks, when in reality there are no data for those stocks. Making a simplified index using the tag data, and expanding it for different geographical regions is the best that the ISBM index is capable of doing, and it should be limited to that at most. A simplified index would thus track exploitation for broad geographical locations such as the lower Columbia, upper Columbia, Oregon Coast, Washington coast, Puget Sound, lower and upper Fraser, and the west coast of Vancouver Island. There may be stock differences for stocks in close proximity to one another (as shown by Hilborn et. al. 2003 for sockeye salmon in Bristol Bay), but unless data are available to quantify such differences it is pointless to generate indices for individual stocks.

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APPENDIX 1: CURRENT LIMITATIONS ON THE ISBM INDEX (FROM ISBM 2005)

1.1 LOGISTICAL PROBLEMS ON DATA REPORTING

The calculation of pre-season model-based indices are followed by a post-season evaluation using coded wire tags (CWTs) two years later. Tagged data takes a while to process and input into the Regional Mark Information System (RMIS), a centralized data base. As such, for 2 years after the fisheries have occurred, the ctc has no means of assessing whether the target ISBM index objectives were met for a certain stock, though managers will report on whether agreed escapement objectives have been met for that stock or stock aggregate. In the case when the stock achieves its escapement goal, this is a moot point. However, if a stock doesn't meet its escapement objectives, concerns have arisen as to the intent of ISBM provisions of the Chinook chapter is being fulfilled by the managers.

There may be possible alternatives that can be used to measure ISBM compliance where escapement goals are not being met if we change the way we produce post-season assessments. If the model is used to assess post-season performance with the AI's and CWT data are not used to assess ISBM compliance), a potential alternative may exist to address this management concern. This alternative would require projecting FP's or ceiling catches for all the associated fisheries and then computing an ISBM index from the model but this time with observed rather than projected harvest rates (that the CTC does preseason) on the stocks of concern.

1.2 POST-SEASON PERFORMANCE (CWT VERSUS MODEL)

An analysis was performed on pre and post season estimates of ISBM indices. Two measures of performance were examined. When both pre and post season data (between 1999 and 2003) were available, correlations to define how the indices tracked one another were computed. For the other measure, bias between the projected ISBM index using the Chinook model and what happened using the CWTs was assessed.

1.2.1 US ISBM FISHERIES

1.2.1.1 PUGET SOUND

There are only 3 years of CWT data for the Stillaguamish and Nooksack Springs. While the Stillaguamish post-season ISBM index tracks the pre-season index trend well, it seems to be underestimating the impacts using the model. In this region, there is no information available to evaluate the Skagit, Snohomish, Lake Washington and Skagit Spring Chinook stocks as there areno CWT data to represent what happened to these stocks post season (Figure 1.1). The only stock with adequate coverage in Puget Sound is Green River as even the Stillaguamish fall and Nooksack springs tagging programs were stopped in the early 2000s, due to funding cuts.

A possible solution is to take the Green River CWT data and then adjust the recoveries with stocks from the base period (creating a new base) and then calculating an index based on that new base. However this has major assumptions associated with the tag code and may not be entirely appropriate.

Table 1.1: Correlation of pre and post season for Puget Sound stocks (Fall and Spring)

Stock	Correlation Coefficient (ρ)	Avg Bias ((Post-Pre)/Post)
Skagit F	NA	NA
Stillaguamish	0.9963*	-71%

Snohomish	NA	NA
Lake Washington	NA	NA
Green River	-0.169	44%
Skagit Springs	NA	NA
Nooksak Springs	0.1836*	70%

* based on 3 years data

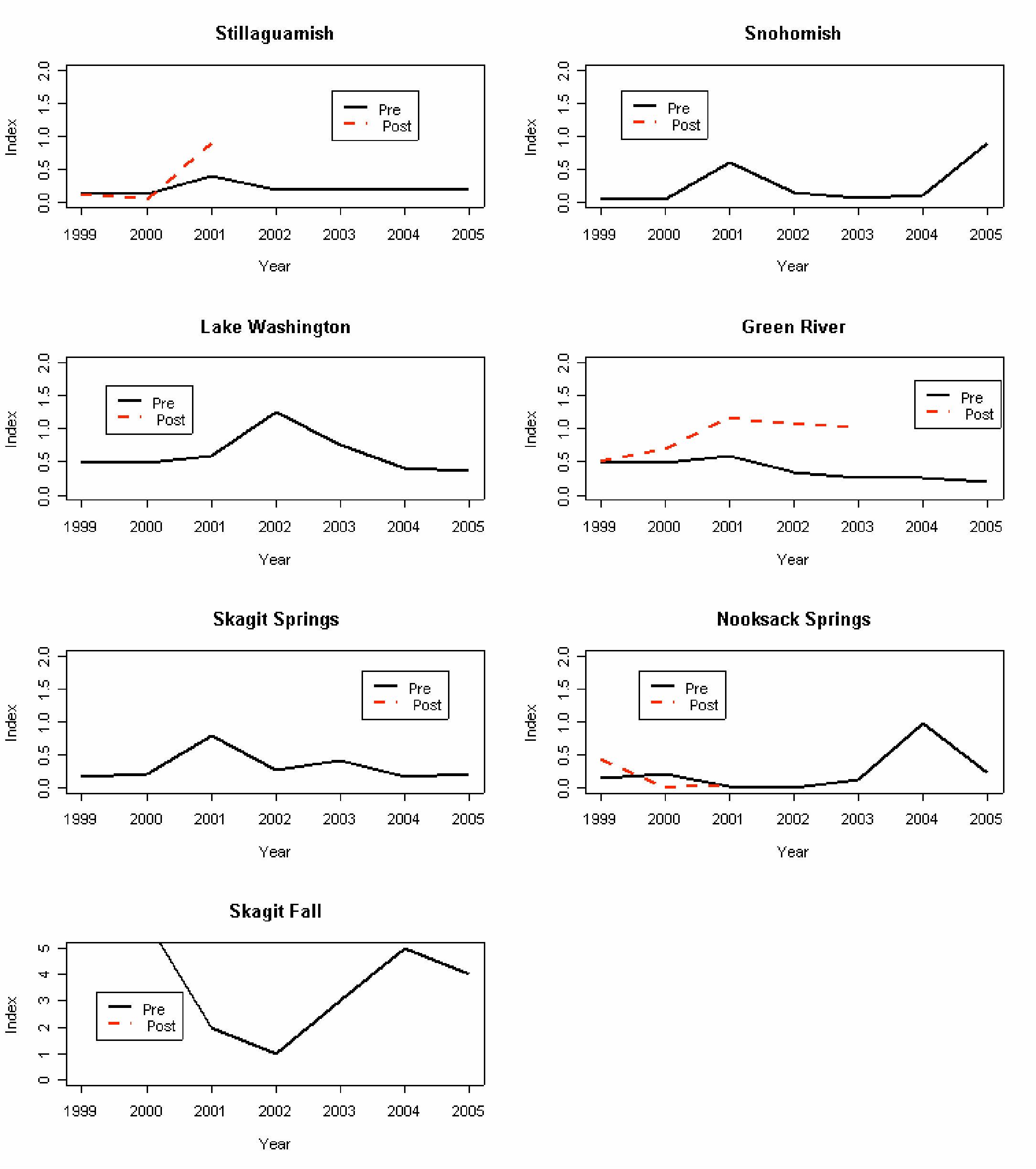


Figure 1.1: Puget Sound pre and post season performance

1.2.1.2 WASHINGTON COAST

Pre and post season bias is lower for the Washington Coastal stock aggregate compared to Puget Sound for this stock complex. However, this may be an artifact of the assumption that the base period tag that maps all the Washington coast stocks is the Queets indicator stock. This may not be entirely accurate and system specific tag codes would be more appropriate. In addition, for stocks such as Grays Harbor, Hoh and Quillayute adjustments are made to terminal tag recoveries based on the harvest rate in those fisheries. Thus recoveries are imputed for certain fisheries. It may be more appropriate to use this same technique directly in the model and compute the recoveries in that manner. Regardless of these problems and inconsistencies, the model appears to be underestimating impacts prior to 2001 (Figure 1.2) and overestimating these impacts in 2002 and 2003. Further investigation of the manner in which fisheries were conducted in 2002 and 2003 may clarify why the model seems to underestimate the ISBM index prior to 2001 and overestimate the ISBM index after 2001.

Table 1.2: Correlation of pre and post season for Washington coast stocks

Stock	Correlation Coefficient (ρ)	Avg Bias ((Post-Pre)/Post)
Hoko	NA	NA
Grays Harbor	-0.28	-33%
Queets	-0.55	16%
Hoh	-0.72	23%
Quillayute	-0.74	22%

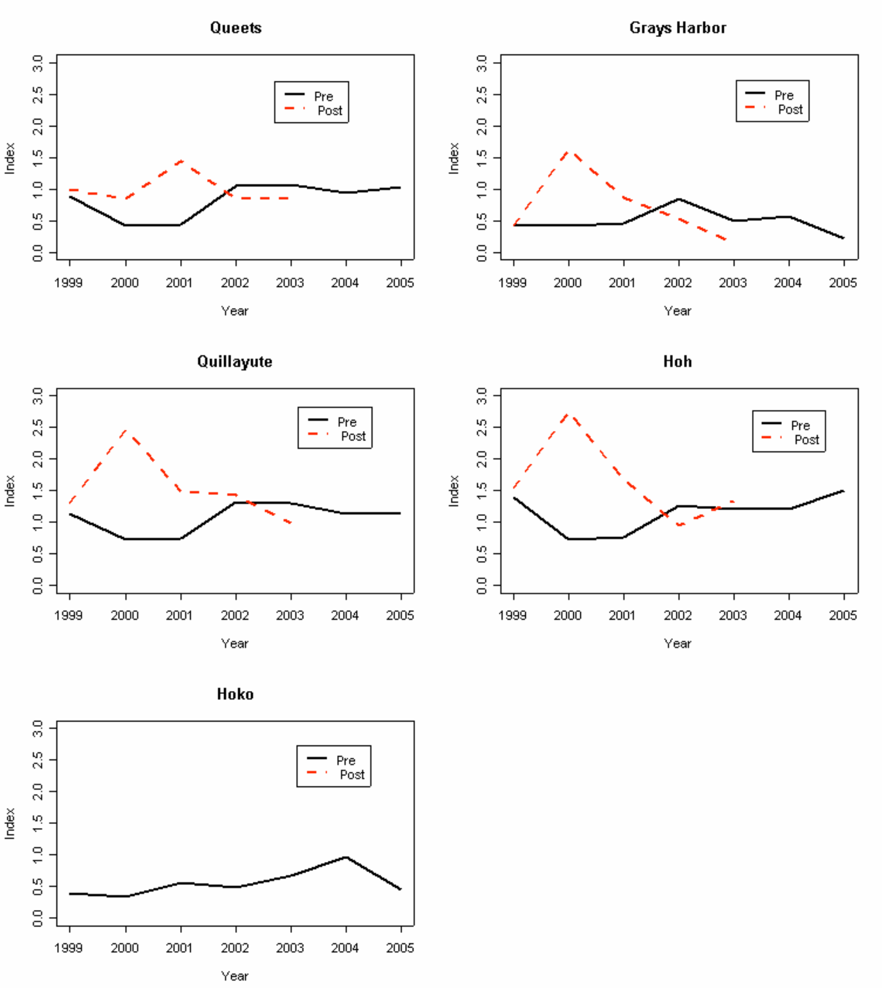


Figure 1.2: Washington coast pre and post season performance

1.2.1.3 COLUMBIA RIVER AND OREGON COAST

The Columbia River is one of the only systems which has adequate tag code representation of the stock aggregates that are being monitored, both preseason and post season. However, the indices do not track the model well (Figure 1.3). Even though the overall trend may be captured, the post season analysis on the Upriver Bright population is always higher than the pre-season model. The Deschutes and the Lewis post season indices are consistently below the pre-season estimate.

The Mid Columbia Summer ISBM index is consistently underestimated by the model (Figure 1.3). This may be due to several factors for this stock. For example, in recent years the terminal harvest levels have increased as a result of the reduced interim escapement goal for this stock relative to the base period and also the CWT group of fish (marked populations) is also mass marked and is subjected to selective fisheries management strategies.

The Oregon Coast stocks seem to track well in the pre and post season (Figure 1.3). However, the abundance of both the Siletz and Nehalem appear to be over-predicted by the model. The Siuslaw seems to perform better than the other two though the average bias is positive in this case. The Oregon coast has similar problems as the Washington coast where the Salmon River indicator tag program is used to evaluate the impacts of these fisheries, and create pseudo recoveries in terminal fisheries based on harvest rates observed in those fisheries. It would be more appropriate to have indicator programs on each of these rivers.

Table 1.3: Correlation of pre and post season for Columbia River and Oregon coast stocks

Stock	Correlation Coefficient (ρ)	Avg Bias ((Post-Pre)/Post)
Upriver Brights	0.40	38%
Deschutes	0.19	-35%
Lewis River	0.56	-47%
Mid-Columbia Summers	0.83	94%
Nehalem	-0.98	-22%
Siletz	-0.76	-43%
Siuslaw	0.65	27%

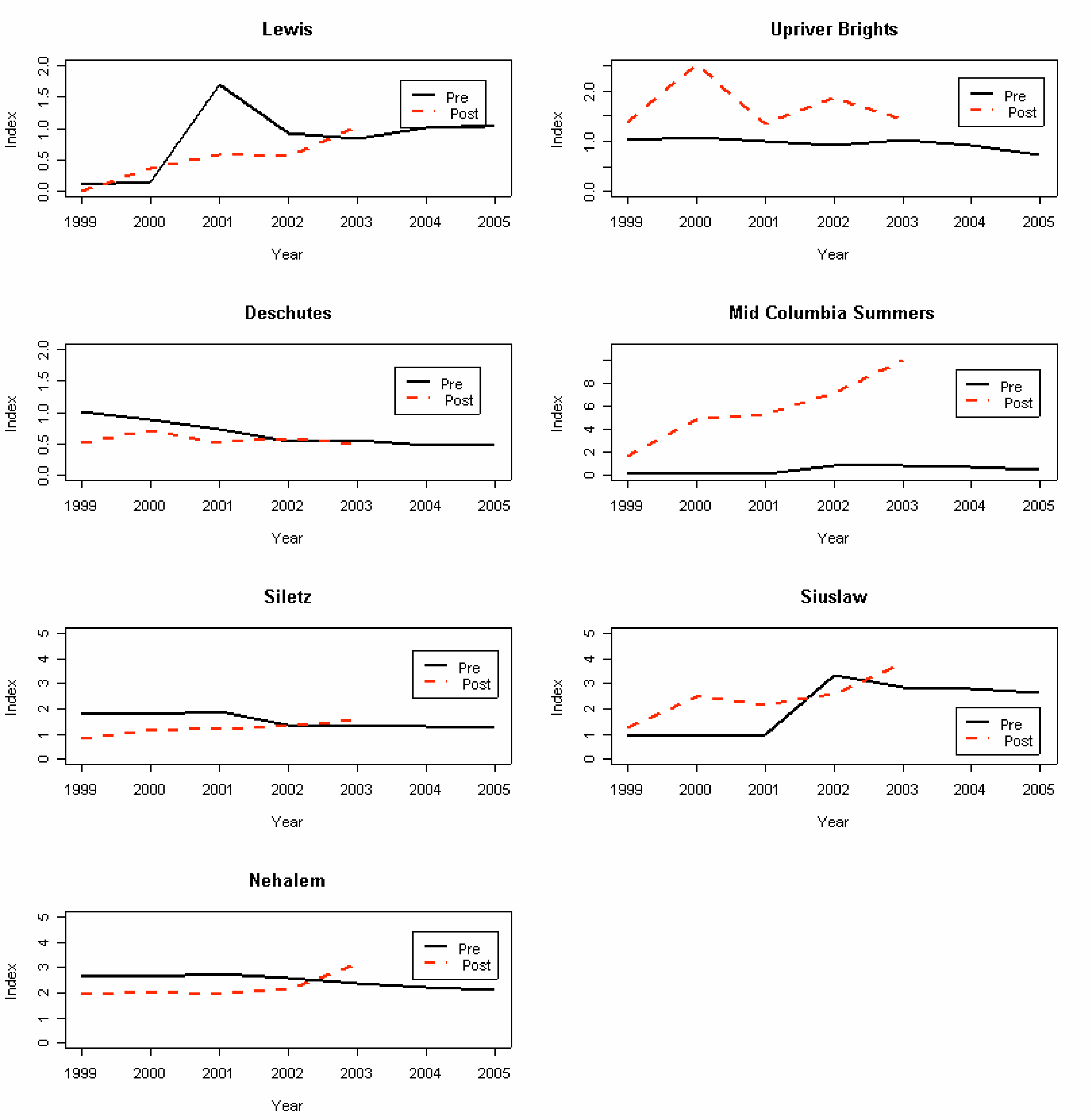


Figure 1.3: Oregon coast pre and post season performance

1.2.1.4 CANADIAN STOCKS

The Canadian stocks encountered in US fisheries with adequate tag recoveries and coverage are the Harrison River, the Nanaimo and the Cowichan (Figure 1.5). The Harrison seems to be over-predicted by the model, but the Lower Georgia Straits (namely the Cowichan and Nanaimo) seem to be under-predicted (the magnitude of the bias is very high for the Lower Georgia Strait stock group), and the reason for this is probably due to the low exploitation rate in these fisheries

Table 1.4: Correlation of pre and post season for Canadian stocks

Stock	Correlation Coefficient (ρ)	Avg Bias ((Post-Pre)/Post)
Harrison	0.93	-104%
Cowichan	0.89	87%
Nanaimo	0.89	0
Fraser Early	NA	NA
WCVI	NA	NA

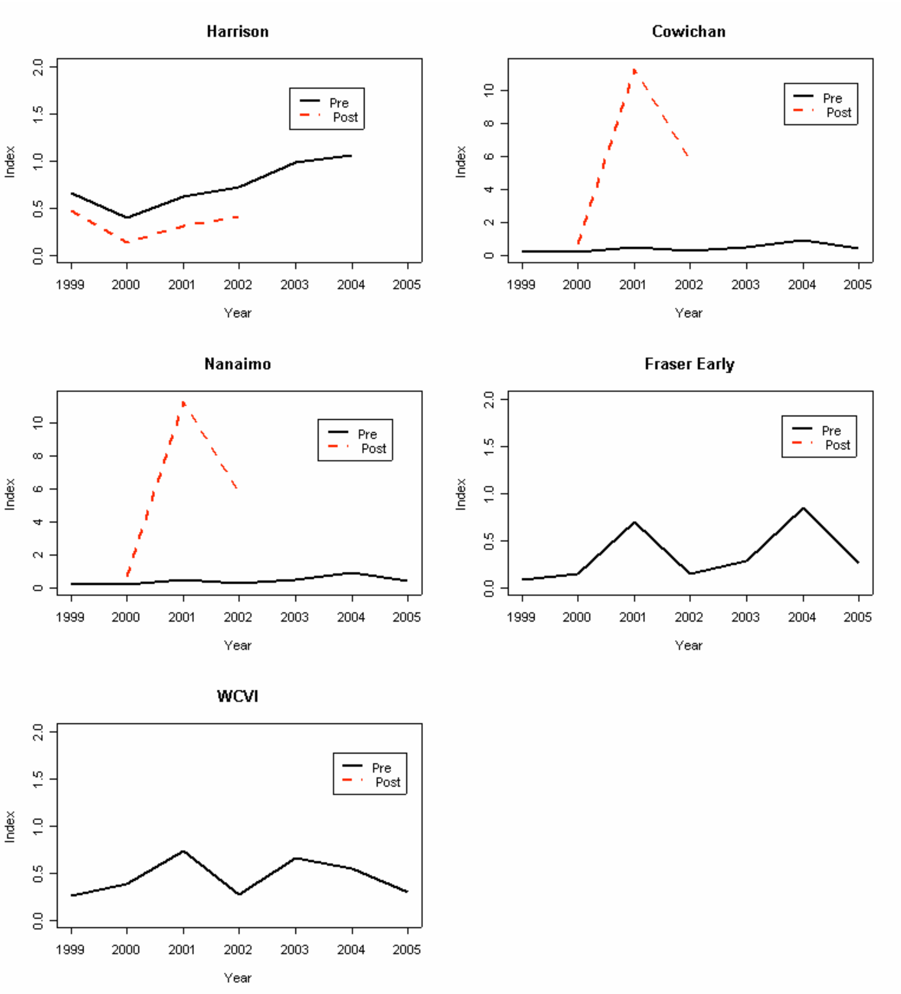


Figure 1.4: Canadian pre and post season performance (Stocks not included are Upper Georgia Strait and North Central BC).

During the base period. However, both sets of data use the model base period information (table 1.5) and hence these inaccuracies may be entirely due to using the model base period data.

1.2.2 CANADIAN ISBM FISHERIES

Canadian fisheries and stocks were also evaluated using similar criterion as the US fisheries. Although the Canadian CWT coverage had with a much longer tagging history in certain cases, is not as extensive as the US stock coverage. Hence, assumptions about relationships between an individual tagging program and how it relates to larger spatial areas have to be made. This may be one of several limitations of calculating a meaningful index for these areas.

Table 1.5: Correlation of pre and post season for Canadian stocks in Canadian ISBM fisheries

Stock	Correlation Coefficient (ρ)	Avg Bias ((Post-Pre)/Post)
Cowichan	-0.01	-31%
Nanaimo	0.67	7%
Upper Georgia Straits	-0.67	-2492%
FRL (Harrison)	0.02	-270%
Upper Fraser	NA	NA
WCVI	0.78	-135%
Northern BC	NA	NA

1.2.2.1 LOWER STRAIT OF GEORGIA (COWICHAN & NANAIMO)

This is the only stock complex that has adequate coverage with both stocks having CWT representation. In recent years however, it has been pointed out that the Nanaimo stock has no representation in the base period and the Cowichan stock has been used as a surrogate for modeling and management purposes. For that reason, computation of post season indices for the Nanaimo are being discontinued. In addition, methods to disaggregate the Cowichan and the Nanaimo stocks have not been done correctly, and CDFO has decided to keep the Lower Georgia Strait stock complex as one group and not disaggregate it as has been done in the past. The pre and post season estimates track quite well (figure 1.5). However, the manner in which Nanaimo was treated from the model may have been inaccurate and as a result the CTC is no longer computing the index for Nanaimo , even though it had the lowest bias of any ISBM stock being analyzed.

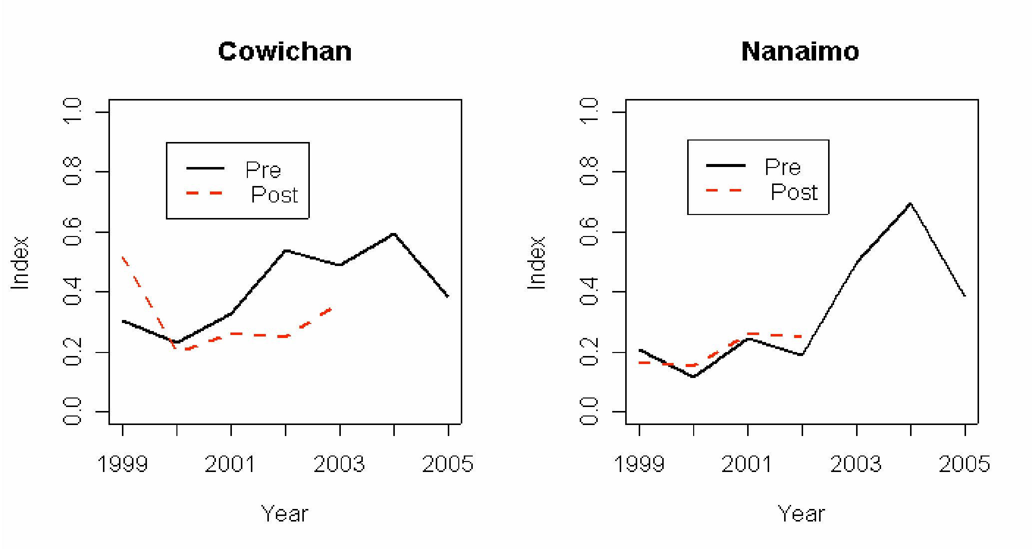


Figure 1.5: Pre and post season performance for Lower Georgia Strait ISBM fisheries

1.2.2.2 UPPER STRAIT OF GEORGIA (KLINAKLINI, KAKWEIKAN, WAKEMAN, KINGCOME, NIMPKISH)

Upper Georgia Straits stocks are represented by Quinsam hatchery. This is a fairly extensive area and the coverage is fairly limited by the use of just one indicator stock for this area. The fisheries on this stock have been completely eliminated due to depressed Chinook population status on stocks inside Georgia Straits. As such, the model and the CWT data are completely inconsistent and the worst of any of the stocks analyzed. The degree of bias is extremely high (>2000%) and so is the poor correlation (Table 1.5).

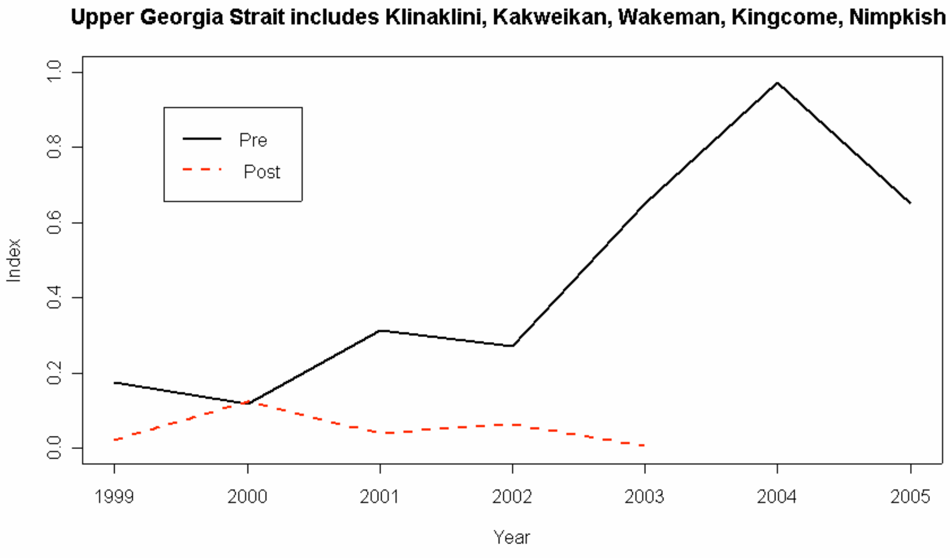


Figure 1.6: Pre and post season performance for Upper Georgia Strait ISBM fisheries

1.2.2.3 FRASER LATE (HARRISON)

Fraser Late is one of the only stocks that have both a model component as well as a hatchery component. However these two sets of data don't track very well (Table 1.5). The structural changes in some of the West Coast of Vancouver Island fisheries may be partially responsible for these changes. However, the fact that there is a mixing of some base period exploitation rates from the model when comparing the existing CWT recovery data may also be partially responsible for the poor correspondence.

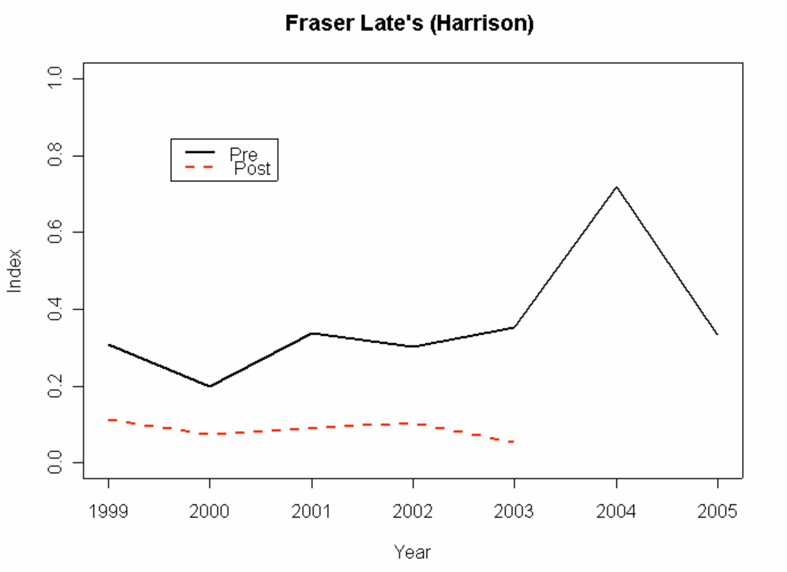


Figure 1.7: Pre and post season performance for Fraser Late's ISBM fisheries

1.2.2.4 FRASER EARLY (UPPER FRASER, MID-FRASER, THOMPSON)

This stock grouping covers a fairly large area of the upper Fraser and includes several depressed Chinook stocks. However, there is no indicator tag program to assess impacts on this stock post-season as is shown below (Figure 1.8). If the model is accurate, the impacts on this stock have been consistently rising with the increase in the Abundance Index and associated allowable catch for the WCVI ocean fisheries.

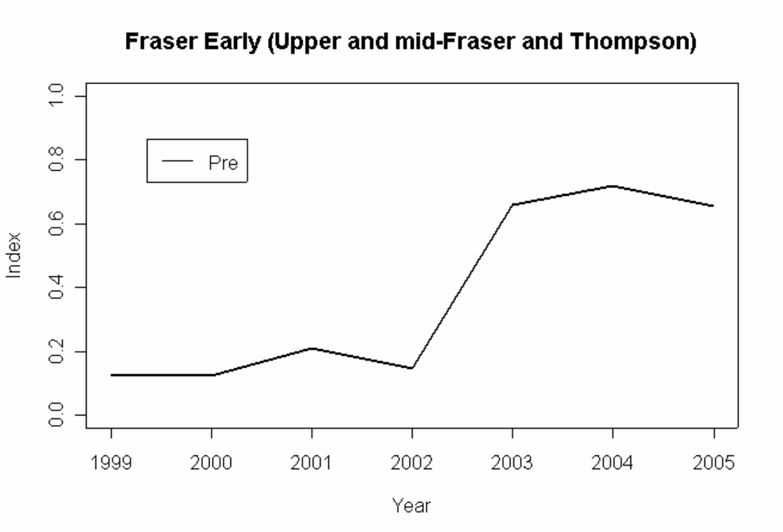


Figure 1.8: Pre season performance for Fraser Early ISBM fisheries

1.2.2.5 WEST COAST OF VANCOUVER ISLAND FALLS (ARTLISH, BURMAN, GOLD, KAUOK, TAHSIS, TASHISH, MARBLE)

The West Coast of Vancouver Island covers a distance of greater than 600 kilometers in length. However, only one indicator tag group, from the Robertson Creek hatchery (in and around Barkley Sound, Figure 1.9) is used to model impacts on seven different river systems. This single index tracks fairly well (Figure 1.9 and Table 1.5) though, and is biased low relative to post season indices compared to pre-season estimates.

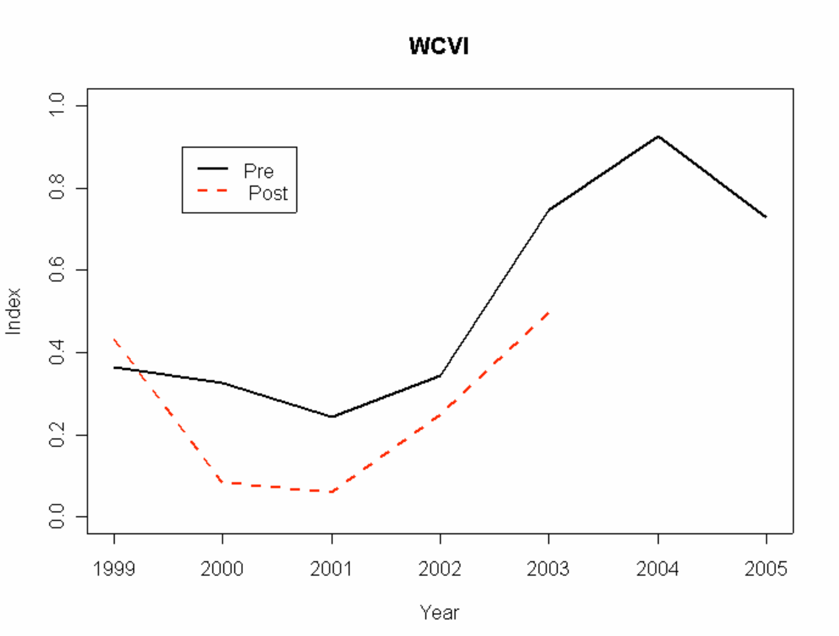


Figure 1.9: Pre and post season performance WCVI ISBM fisheries

1.2.2.6 NORTH/CENTRAL BC (YAKOUN, NASS, SKEENA, AREA 8)

The North central BC area is an extremely large area, but no indicator tag codes are representative of the impacts in this region due to poor recoveries in these fisheries. Hence, there is no post season tracking of the ISBM index. However, if we track this index for all of these stocks, and if the model is accurate, it appears that the index has been increasing due to the larger fisheries in recent years (Figure 1.10).

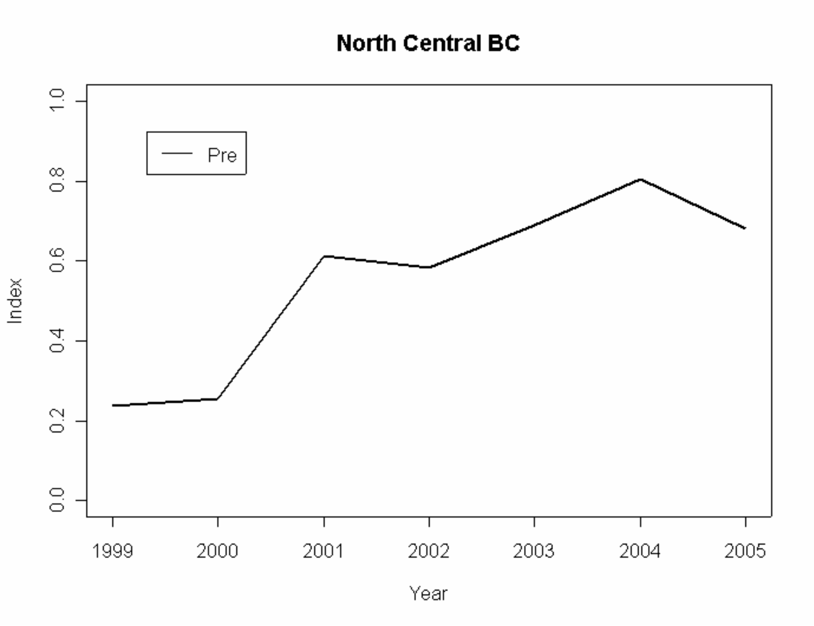


Figure 1.10: Pre season performance NCBC fisheries

1.2.2.7 US STOCKS (WITH CWT INDICES STILLAGUAMISH AND GREEN RIVER)

Post season indices for the Green River and Nooksack Springs are available until 2003. However, the tag code used for Nooksack Springs is questionable. The Stillaguamish has some incomplete coverage as the tagging program was stopped in recent years as a result of decreased funding. For that reason, the Green River is the only real indicator stock to measure what the harvest impacts are in Puget Sound fisheries. Regardless of the limited information due to reduced tagging programs and few indicator stocks, the index is biased low for all three cases (Table 1.6). This is likely due to the harvest management restrictions put in place to address weak stock and ESA concerns.

Table 1.6: Correlation of pre and post season for US stocks in Canadian ISBM fisheries

Stock	Correlation Coefficient (ρ)	Avg Bias ((Post-Pre)/Post)
Nooksack Springs	-0.82	-327%
Skagit Springs	NA	NA
Skagit Falls	NA	NA
Stillaguamish	0.42	-139%
Green	0.56	-34%
Lake Washington	NA	NA
Snohomish	NA	NA
Washington Coast (Queets)	NA	NA

Lewis River	NA	NA
URBS & Deschutes	NA	NA
Columbia Upriver Summers	NA	NA
Northern Oregon Coast	NA	NA

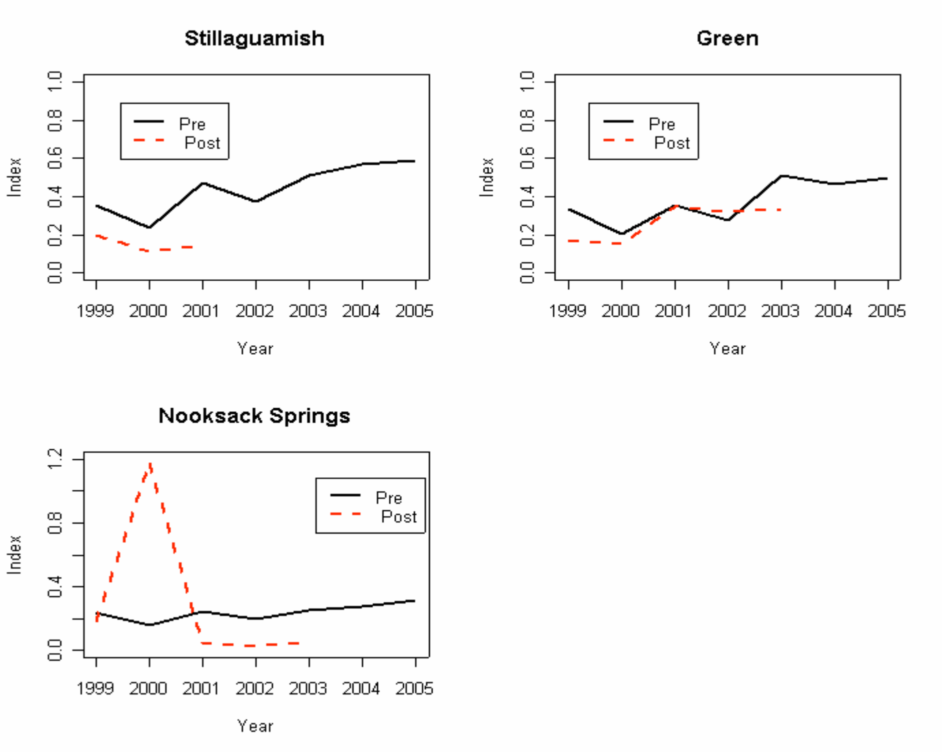
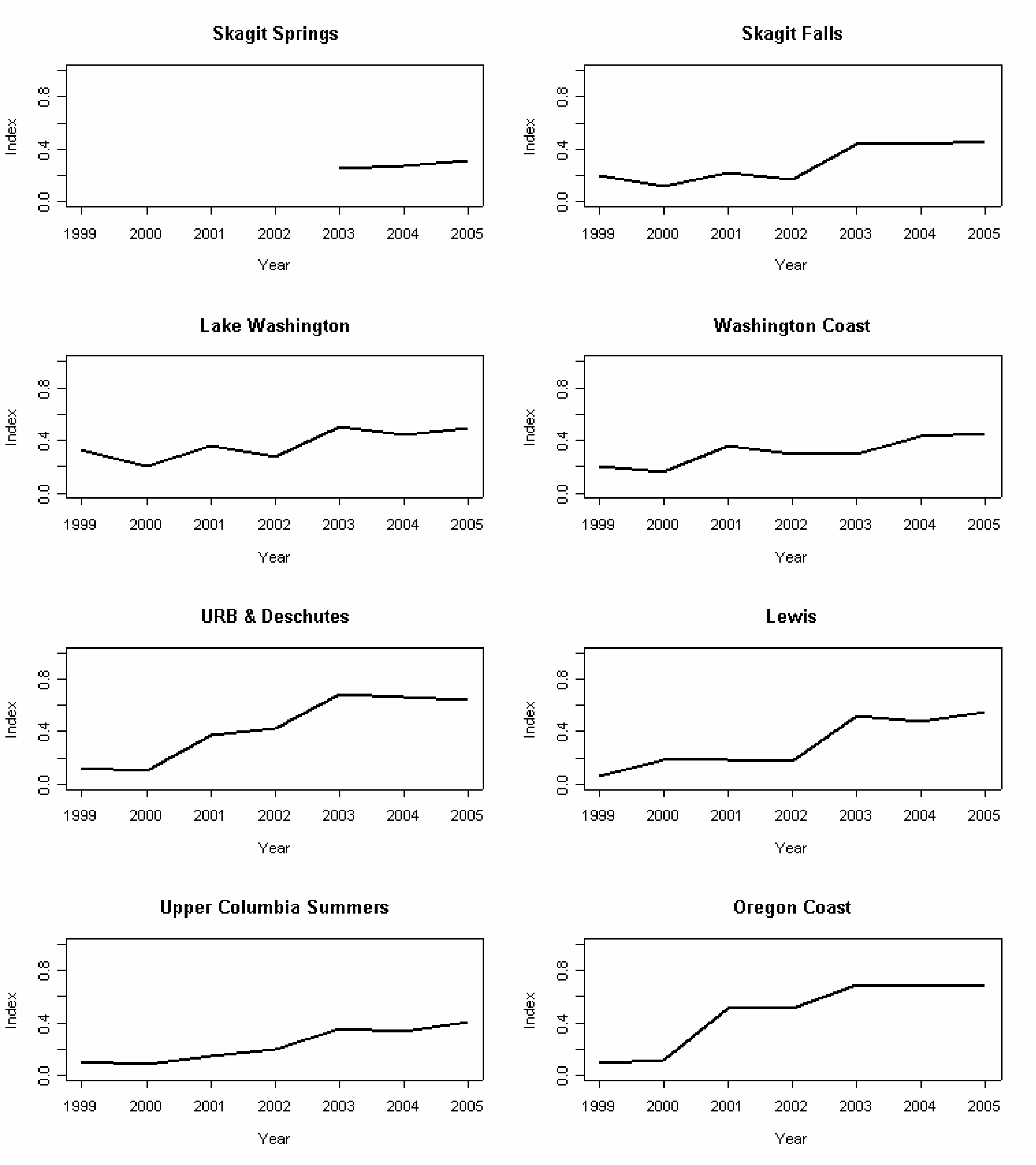


Figure 1.11: Pre and post season performance On US-stocks with sufficient CWT recoveries

1.2.2.8 OTHER US STOCKS WITH INSUFFICIENT CWT DATA

Due to inadequate tag recoveries in Canadian fisheries, there are no post-season performance evaluation measures for the other US stocks (Figure 25). Most of the Puget Sound and Washington Coast stocks appear to be below the allowable impact (Figure 25), but Columbia River and Oregon Coast impacts seem to have increased in recent years based on the model. In all cases though, escapement goals are being met or fisheries are severely restricted or closed in order to meet escapement objectives over the long term.



Skagit Springs

Skagit Falls

Lake Washington

Washington Coast

URB & Deschutes

Lewis

Upper Columbia Summers

Oregon Coast

Figure 1.12: Pre season performance on other US stocks with insufficient CWT recoveries

1.3 DATA PROBLEMS

Issues with data quality are ignored while computing this index. The index is always computed relative to the 1979 to 1982 base period. However, insufficient recoveries or tags from some key programs (and fisheries) are missing in those years in the base period. In addition, fishing patterns have significantly changed from the base period, which makes a direct comparison problematic. Finally, problems with sampling issues in recent fisheries (either because mark selective fishery management techniques are being used or because of budget cuts that have reduced or eliminated monitoring and evaluation programs) makes this index even harder to compute.

1.3.1 BASE PERIOD DATA ISSUES

The ISBM ceiling index has an implicit assumption that the fisheries or fishing structure should not have changed drastically relative to the base period. This assumption is seriously flawed as, due to conservation concerns, overall harvest rates for these fisheries have been drastically cut back, especially since 1990 (Figures 1.13 and 1.1.4 are computed using equal weight to terminal and pre-terminal fishery harvest rates). The histograms, which are based upon data on which there were indices computed for each jurisdiction in 2003, show that relative to the base period CWT data for stocks on which we compute this index, harvest rates have dropped for both the Canadian and the US jurisdictions.

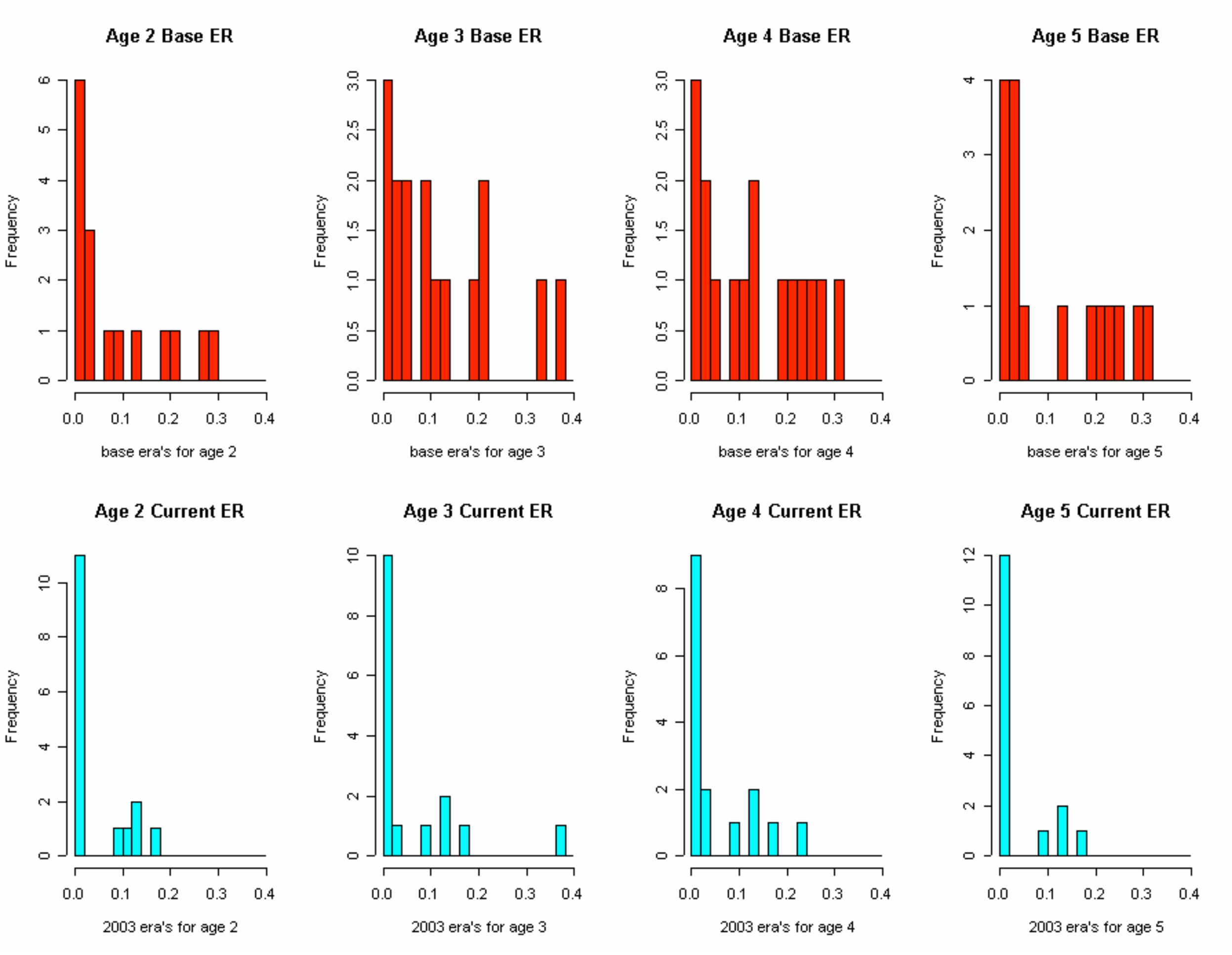


Figure 1.13: Base period exploitation based on CWT data versus current (2003) exploitation rates by age for Canadian ISBM indices that are computable

In the US a similar pattern also exists for stocks for which CWT data are available and an index caqn be computed (Figure 1.14). The mode and skew of the distributions in harvest rates (Figure 1.13 and 1.14) have all shifted to the left from the base to the current time (2003 calendar year) indicating that exploitation rates have dropped significantly in these fisheries even though the overall abundance was fairly high in the ocean for most Chinook stocks in 2003.

Regardless, survivals in the late 1970's and early 1980's were high. Fisheries were operating at their peak during that period in various ISBM fisheries. Since then, gear modifications and time and area closures have moved these fisheries to more compressed seasons with complete elimination of fisheries in certain areas. Hence the assumption that fisheries today are similar to the base period may no longer be valid.

The opposite has happened in some areas. For instance, fisheries on the Oregon Coastal Chinook in the Siletz and Siuslaw were practically non-existent during the base period (Table 1, Appendix 11 in Sharma 2005). Since then, a major in-river sport fishery has been developed on these stocks and hence ISBM index is higher. This is true in the case of the Columbia Upriver Summers as well, where the CTC has adopted and managers are using a dramatically reduced interim escapement goal.

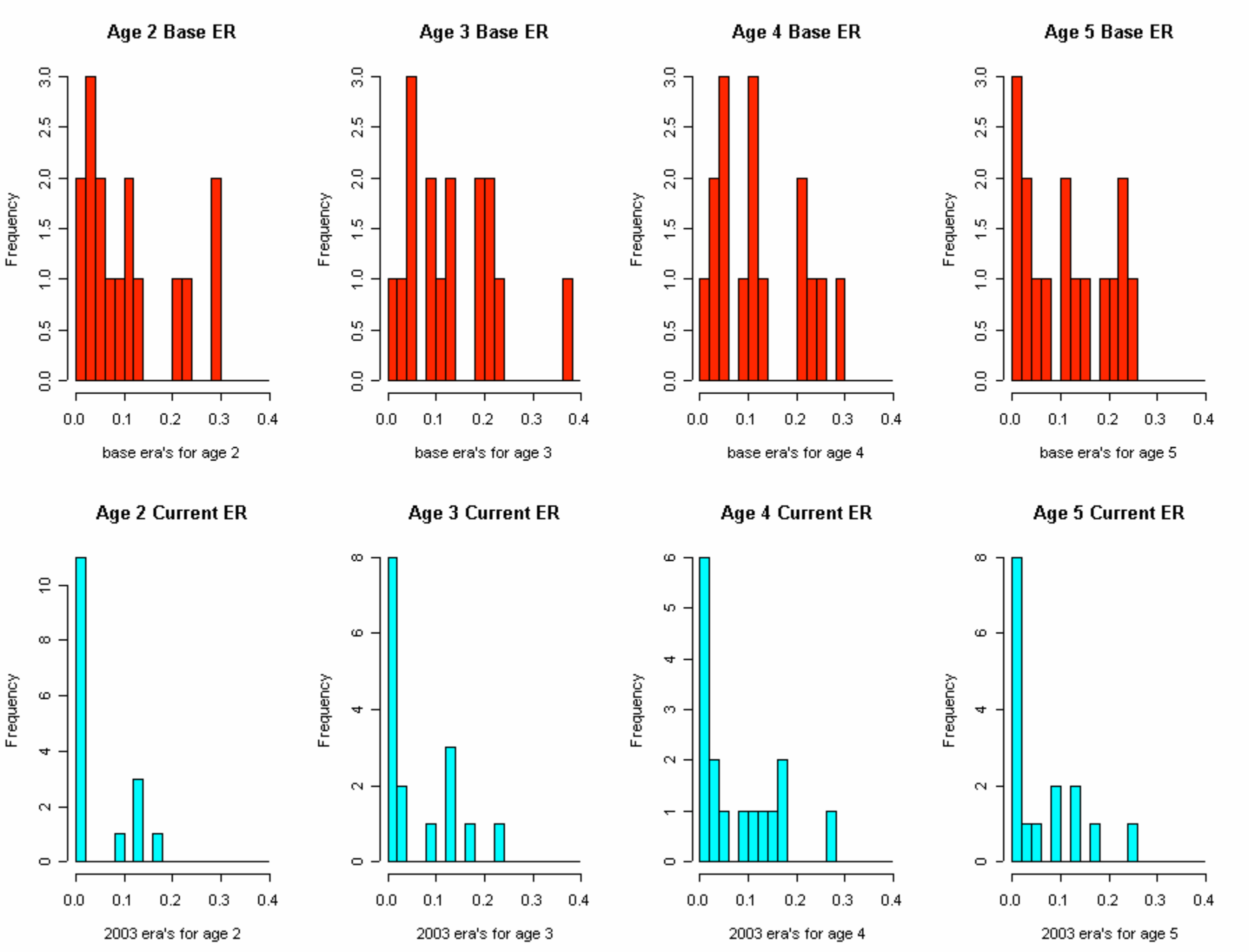


Figure 1.14: Base period exploitation based on CWT data versus current (2003) exploitation rates by age for US ISBM indices that are computable

Ideveloped an absolute measure of fishing intensity using the following equation that we call the ERI:

$$ERI_t = \frac{\sum_{i=2}^{5} C_{i.f}}{\sum_{i=2}^{5} A_{i,f}}$$

where C is the catch in an ISBM fishery (by age (i)) and A is the abundance in the fishery (either terminal or pre-terminal).

The CTC weighted this index by terminal and ocean fisheries (equal weight). Our rational to do so was the fact that these indices were based on different abundances in terminal and pre-terminal fisheries, but we were uncertain as to the magnitude or direction of bias that the index would be depending on what we chose as our weights..

Figure 1.1.5 shows the relative index of fishing intensity on the different CWT stocks for which we currently estimate an ISBM index. Both the Canadian and the US ERI have significantly declined in recent years as compared to their base period fisheries. However, for some stocks, such as the Oregon coastal stocks and the Columbia Upriver Summers, the ERI has increased, suggesting an increase in the overall exploitation relative to the base. In the US ISBM fisheries, the harvest impacts on the Cowichan stock have also increased relative to the base period.

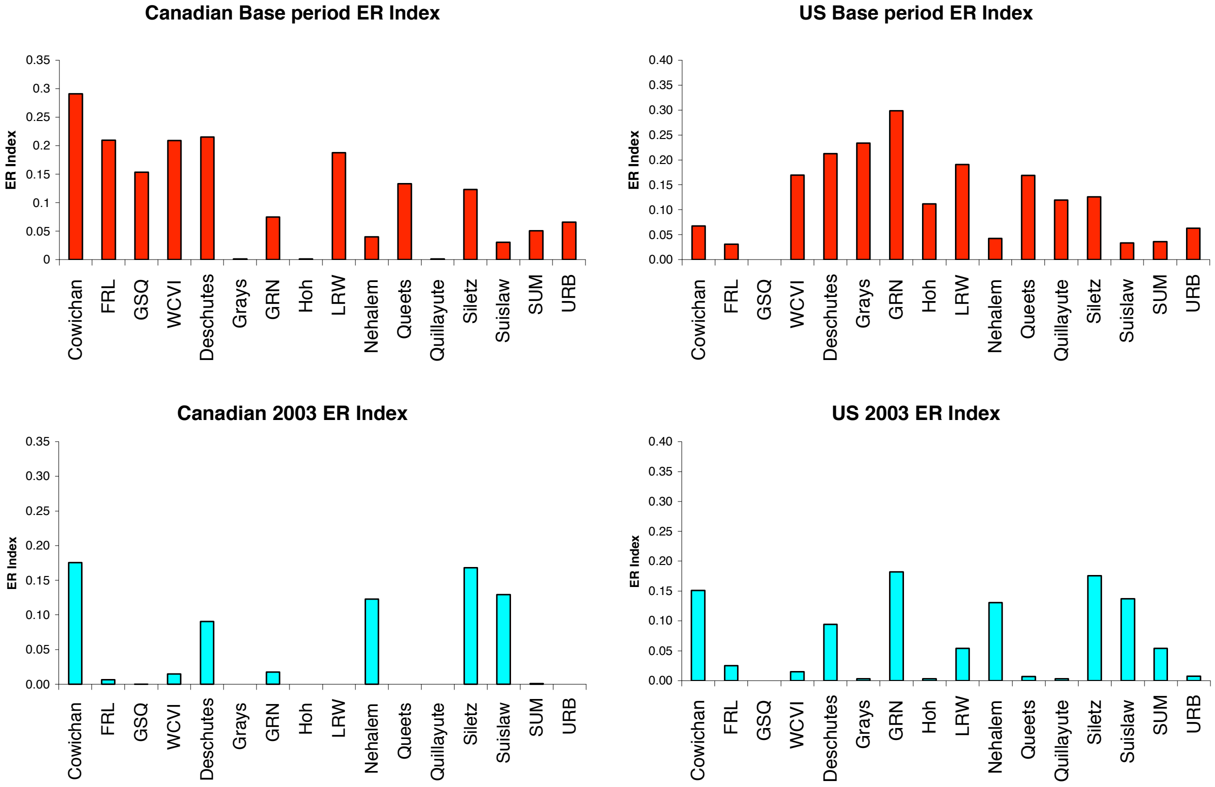


Figure1.1.5: Exploitation Rate Index for different stocks in US and Canadian ISBM fisheries

Finally, numerous tag programs began after the base period and even though some assessment data may be collected currently, these codes have no base period data and so assumptions need to be drawn from other tag codes or stock groupings to assess the base data (Table 1.7).

Table 1.7: Tag programs with limited base data

Stock Group	ISBM Stock	CWT Stock	Stock associated with Base data from STK file
Lower Strait of Georgia	Cowichan Nanaimo	Cowichan Big Qualicum River	GST
Fraser Late	Harrison	Chilliwac	FRL
North Puget Sound Natural Spring	Nooksack Spring Skagit Spring	Nooksack Spring N/A	NKS
Puget Sound Natural Summer/Falls	Skagit Stillaguamish	N/A Stillaguamish Fall Fing	SKG base period HR STL

1.3.2 INADEQUATE COVERAGE OF CWT STOCKS

Inadequate CWT coverage has two degrees of complexities. For the base period data, assumptions and linkages were made for Fraser Early, North Central BC and Puget Sound and how they relate to the model. However, there are no tag codes to represent these stocks in a post season evaluation. Hence, the model must be used to directly generate these estimates, without any way to verify the accuracy of these estimates post season (Table 1.8).

Table 1.8: Stock groups with no CWT coverage

Stock Group	ISBM Stock
Fraser Early (springs and summers)	Upper Fraser Mid Fraser Thompson
North/Central BC	Yakoun Nass Skeena Area 8
Puget Sound	Snohomish Skagit Falls Skagit Springs Lake Washington*

*this stock had base coverage but in recent years there is no tagging from UW

While not as serious a problem, harvest data in terminal fisheries for most of these stocks were derived from certain indicator stocks. The CTC assumes a single stock represents many stocks, e.g. Queets represents most of Washington coast, Salmon River represents all of Oregon coast. This may be problematic as these are all independent stocks and only stock is used to represent a large area. In a study by Hilborn et. al. (2003), for a highly studied Bristol Bay sockeye system, populations even in very close proximity to one another had very different survival and exploitation. Thus assuming that one tag code represents the dynamics of all stocks may be misleading as the stocks may behave very differently in the ocean. A list of the stock groups that are represented by a tag code of another system are listed below (Table 1.9)

Table 1.9: Stock groups with associated coverage from another system

Stock Group	ISBM Stock	CWT Stock associated from another system
Upper Strait of Georgia	Klinaklini Kakweikan Wakeman Kingcome Nimpkish	Quinsam
West Coast Vancouver Island Falls	Artlish Burman Gold Tahsis Tashish Marble Kauok	Robertson Creek
Washington Coastal Fall Naturals	Grays Harbor	Queets
	Hoh	Queets
	Quillayute	Queets
Col River Falls	Deschutes	Upriver Bright
Far North Migrating Oregon Coastal Falls	Nehalem	Salmon River Hatchery
	Siletz	Salmon River Hatchery
	Siuslaw	Salmon River Hatchery

In Canada there are indicator stocks for very large areas with very little stock specific information (WCVI represents the entire West Coast of Vancouver Island, encompassing 7 individual stocks, while Upper Georgia Strait also represents 5 stocks). For two stock aggregates there is no way to assess performance besides the model estimates because there are no indicator tagged group for these stock aggregates (Table 1.8).

1.3.3 INCONSISTENCIES IN ANALYZING TWO DIFFERENT SETS OF DATA

As a function of limited indicator stock and CWT coverage, the CTC has been forced to mix and match different kinds of data to compute an index. The varieties and differences in the methods used to generate these indices postseason have been shown by Sharma (2005: Tables 4, 6, 7, 8). The problems in making sense out of these indices are further confounded by mixing two different data sources.

In the preseason projections (Sharma 2005, Table 4 and Figure 6) the CTC mixed changes from base for certain stocks from the FRAM model (PFMC 2003) with the CTC-model. In addition, the CTC mixes terminal harvest rates on a stock assuming that the harvest occurs across all ages equally with a model stock complex (Sharma 2005, Table 4 and Figure 7).

For the post season analysis two problems are created. The first issue is that the CTC mixes and matches different base period harvest rates derived from other stocks or data sources and associates them with a stock (Sharma 2005, Tables 7, 8). In some cases the CTC even combines base period data from a different stock with current harvest rates for a particular stock, overwriting the tag based exploitation rate in a certain fishery for that stock. This makes it very difficult to understand whether this index for the stock is meaningful to the base as no data existed for this stock in the base period.

The second issue that arises in the post season analysis is similar to the pre-season analysis where the CTC mixes and matches terminal harvest rates for certain fisheries and overwrites tag data for those fishery specific harvest rates (Sharma 2005, Table 7 and Figure 13). One of these pieces of data is from a hatchery (CWT) while the other information comes from a terminal harvest rate on a wild stock (or hatchery wild composite stock). This may not be that serious an issue, but the result is mixing different pieces of information on fisheries and CWT data to compute this index.

1.3.4 RECENT SAMPLING DATA ISSUES

Due to recent changes in fisheries and budget cuts experienced by agencies, the sampling coverage has decreased in certain fisheries (e.g WCVI troll and sport fisheries). In addition, mass marking has made some of the data gathering issues more prominent, resulting in directed fisheries on tagged stocks which make the index meaningless unless the CWT estimates are corrected in these fisheries for the indicator stocks (SFEC 2002).

Escapement data from some hatcheries are also suspect (JCDAW 2003) and thus if important escapement information is missing (either because of incomplete sampling at the hatchery or because of strays), these indices will not mean much. Further, if the stray rates on indicator stocks or sampling issues have gotten exacerbated in recent years as compared to the base period, estimates and biases become more problematic.

In the current procedure, the CTC mixes terminal harvest rates with CWT data, and this terminal harvest rate is based on catch and escapement data for the system of concern. The CTC is aware of how problematic and imprecise some of these escapement estimates are in some cases; in such cases terminal harvest rate estimates are also meaningless and thus the index is further confounded, and difficult to make sense out of.

1.4 ALGORITHM PROBLEMS

ISBM indices are computed using adult equivalence (AEQ's) rates. However, there are missing data due to incomplete broods for any given year. In this report, I developed a theoretical exercise for an analysis on incomplete versus complete broods I used 2000 calendar year Upriver Brights as an example. Thus, I assume that in year 2000 (as the true AEQ's are not available) average AEQ's for all 3 ages (Appendix 12 Sharma 2005) with the time series prior to 2000. The average method for incomplete broods is compared to the theoretical complete brood (using 2000 Calendar year AEQ's from the 2005 ERA as there are complete broods for the 2000 calendar year by 2003 calendar year). The bias shown in the example developed is 2% but this could be greater or lower depending on the magnitude of difference between the average and true AEQ's.

APPENDIX 2: PREDICTIVED MODELS USING RELEASE, EFFORT AND SURVIVAL DATA

Table 2.1: Parameter estimates using fishery specific data as response and equation 2.2 as the linear predictor

Escapement

Parameters	Estimate	SE	Z-value	Pr(>|z|)
β_0	2.09E+00	1.19E-01	17.621	<2.00E-16
β_1	2.20E+00	1.36E-01	16.174	<2.00E-16
β_2	2.20E+00	1.27E-01	17.239	<2.00E-16
β_3	1.38E+00	1.36E-01	10.106	<2.00E-16
β_4	1.60E-03	1.37E-03	1.172	<2.00E-16
β_5	-1.58E-02	8.63E-04	-18.355	0.24138
β_6	-7.47E-03	7.20E-04	-10.371	<2.00E-16
β_7	-3.32E-03	1.13E-03	-2.926	<2.00E-16
β_8	1.39E-06	1.74E-07	7.981	0.00344
β_9	2.34E-06	9.55E-08	24.497	1.46E-15
β_{10}	3.07E-06	8.17E-08	37.567	<2.00E-16
β_{11}	1.58E-06	1.69E-07	9.337	<2.00E-16
β_{12}	5.02E+01	1.49E+00	33.694	<2.00E-16
β_{13}	2.75E+01	9.76E-01	28.138	<2.00E-16
β_{14}	2.26E+01	5.19E-01	43.478	<2.00E-16
β_{15}	2.93E+01	9.66E-01	30.286	<2.00E-16

Canadian Fisheries

Parameter	Estimate	SE	Z-value	Pr(>|z|)
β_0	-1.60E+00	2.56E-01	-6.25	4.11E-10
β_1	1.33E+00	3.03E-01	4.379	1.19E-05
β_2	1.86E+00	2.86E-01	6.494	8.36E-11
β_3	1.31E+00	3.55E-01	3.692	0.000222
β_4	3.74E+00	2.25E-01	16.616	<2.00E-16
β_5	2.54E+00	1.55E-01	16.386	<2.00E-16
β_6	2.23E+00	1.54E-01	14.425	<2.00E-16
β_7	-2.92E-01	3.58E-01	-0.813	0.416004
β_8	2.98E-06	4.40E-07	6.766	1.33E-11
β_9	2.89E-06	3.47E-07	8.334	<2.00E-16
β_{10}	2.98E-06	3.38E-07	8.811	<2.00E-16
β_{11}	3.95E-06	6.32E-07	6.251	4.07E-10
β_{12}	1.89E+01	2.43E+00	7.796	6.40E-15
β_{13}	2.79E+01	1.85E+00	15.118	<2.00E-16
β_{14}	2.43E+01	2.18E+00	11.131	<2.00E-16
β_{15}	3.25E+01	4.85E+00	6.703	2.04E-11

Terminal Fisheries

Parameters	Estimate	SE	Z-value	Pr(>|z|)
β_0	-5.67E-01	2.89E-01	-1.96	0.05003
β_1	2.51E+00	3.07E-01	8.163	3.26E-16
β_2	3.58E+00	2.95E-01	12.151	<2.00E-16
β_3	2.39E+00	3.08E-01	7.776	7.48E-15
β_4	8.10E-03	3.12E-03	2.6	0.00932
β_5	-3.32E-03	1.07E-03	-3.093	0.00198
β_6	1.04E-02	7.27E-04	14.342	<2.00E-16
β_7	2.21E-02	1.45E-03	15.246	<2.00E-16
β_8	1.90E-06	4.45E-07	4.264	2.01E-05
β_9	3.87E-06	1.43E-07	27.013	<2.00E-16
β_{10}	3.20E-06	8.94E-08	35.763	<2.00E-16
β_{11}	2.44E-06	1.97E-07	12.424	<2.00E-16
β_{12}	6.63E+01	3.46E+00	19.16	<2.00E-16
β_{13}	5.84E+01	1.16E+00	50.267	<2.00E-16
β_{14}	3.26E+01	4.74E-01	68.892	<2.00E-16
β_{15}	1.87E+01	1.04E+00	17.988	<2.00E-16

Other Fisheries

Parameter	Estimate	SE	Z-value	Pr(>|z|)
β_0	-1.35E+00	8.08E-01	-1.674	0.0941
β_1	1.54E+00	8.18E-01	1.883	0.0597
β_2	4.23E+00	8.10E-01	5.22	1.79E-07
β_3	4.44E+00	8.11E-01	5.48	4.25E-08
β_4	1.10E+00	9.42E-01	1.162	0.2451
β_5	3.13E+00	1.38E-01	22.643	<2.00E-16
β_6	1.39E+00	7.70E-02	18.056	<2.00E-16
β_7	-1.13E-01	1.02E-01	-1.106	0.2688
β_8	-2.64E-06	1.37E-06	-1.926	0.0541
β_9	2.90E-06	1.61E-07	18.031	<2.00E-16
β_{10}	3.05E-06	8.70E-08	35.012	<2.00E-16
β_{11}	2.37E-06	1.56E-07	15.218	<2.00E-16
β_{12}	4.47E+01	7.97E+00	5.603	2.11E-08
β_{13}	3.36E+01	8.71E-01	38.553	<2.00E-16
β_{14}	2.86E+01	6.32E-01	45.176	<2.00E-16
β_{15}	3.55E+01	9.29E-01	38.172	<2.00E-16

Pre-terminal Fisheries

Parameters	Estimate	SE	Z-value	Pr(>|z|)
β_0	-4.49E+00	1.48E+00	-3.031	0.00244
β_1	4.13E+00	1.51E+00	2.746	0.00604
β_2	4.70E+00	1.49E+00	3.146	0.00165
β_3	3.76E+00	1.52E+00	2.479	0.01317
β_4	1.76E+00	1.12E+00	1.569	0.11659
β_5	1.45E+00	2.48E-01	5.846	5.03E-09
β_6	7.25E-01	2.93E-01	2.474	0.01337
β_7	-3.99E-02	5.90E-01	-0.068	0.94608
β_8	1.59E-06	1.81E-06	0.883	0.3774
β_9	3.69E-06	3.49E-07	10.586	<2.00E-16
β_{10}	3.00E-06	3.19E-07	9.394	<2.00E-16
β_{11}	4.25E-06	5.52E-07	7.699	1.37E-14
β_{12}	8.85E+01	1.39E+01	6.385	1.71E-10
β_{13}	4.07E+01	3.11E+00	13.092	<2.00E-16
β_{14}	3.46E+01	3.30E+00	10.486	<2.00E-16
β_{15}	3.06E+01	5.97E+00	5.124	3.00E-07

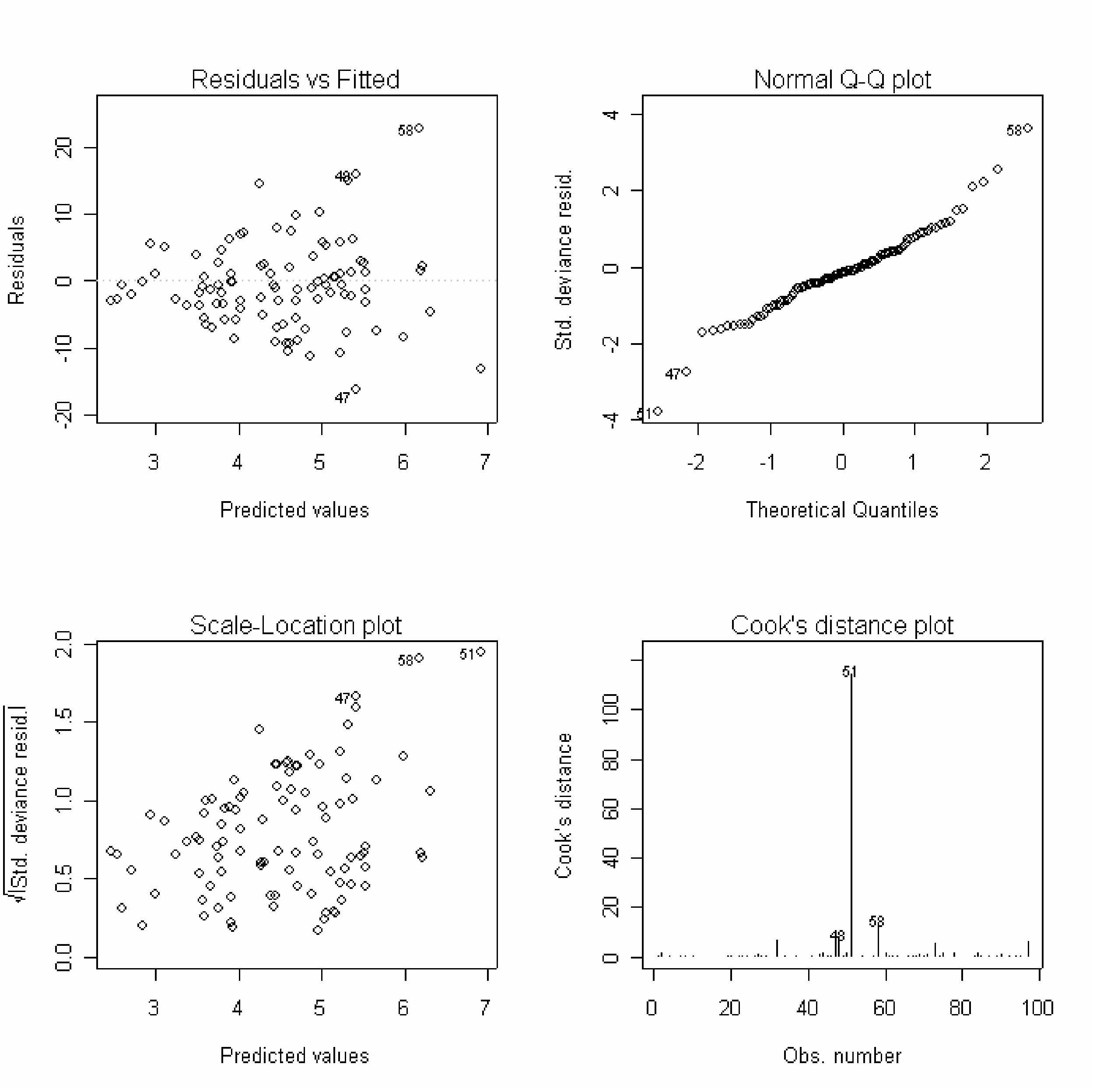


Figure 2.1: Residual Diagnostics over all ages for Escapement

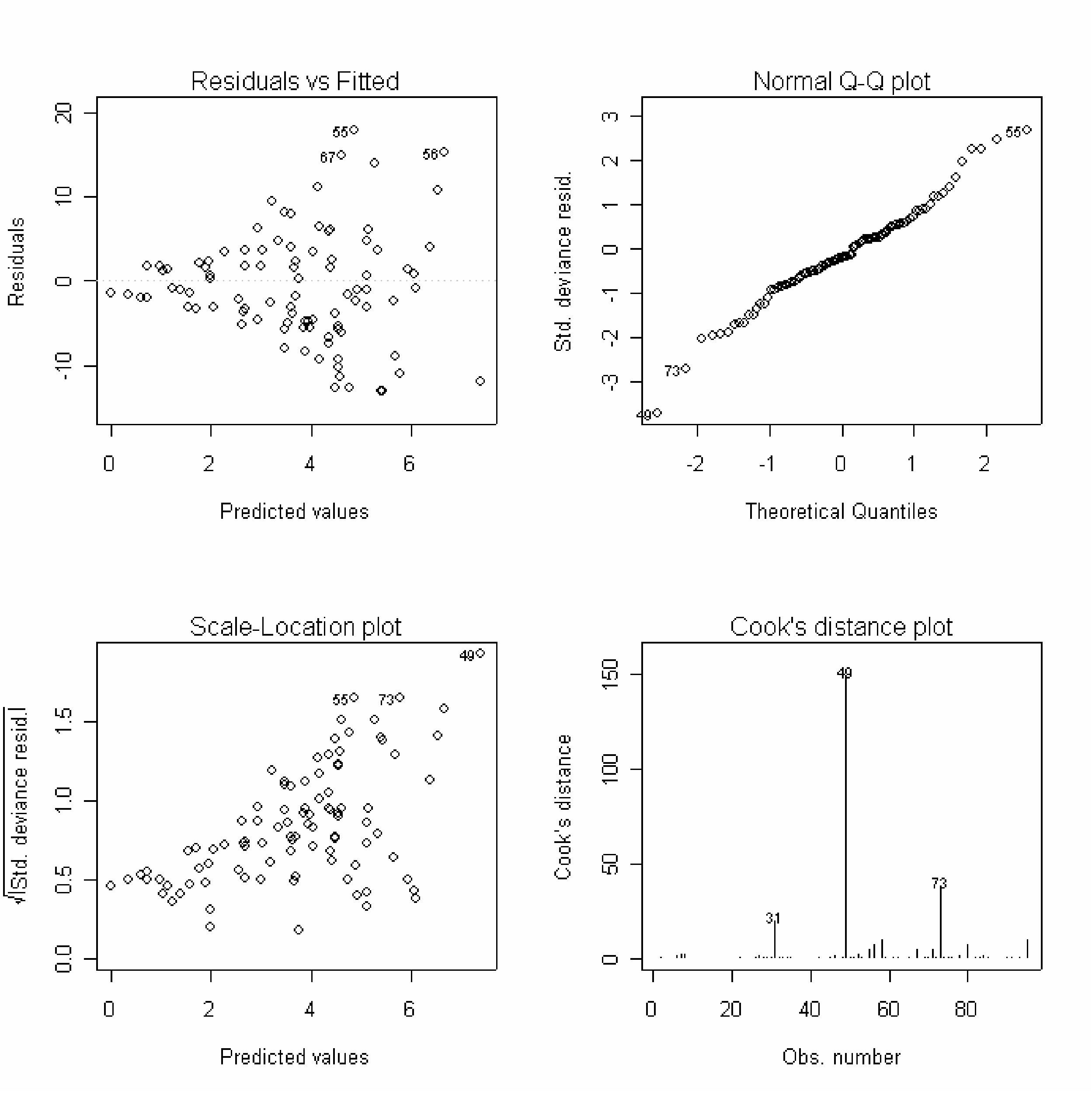


Figure 2.2: Residual Diagnostics over all ages for Terminal US ISBM fisheries

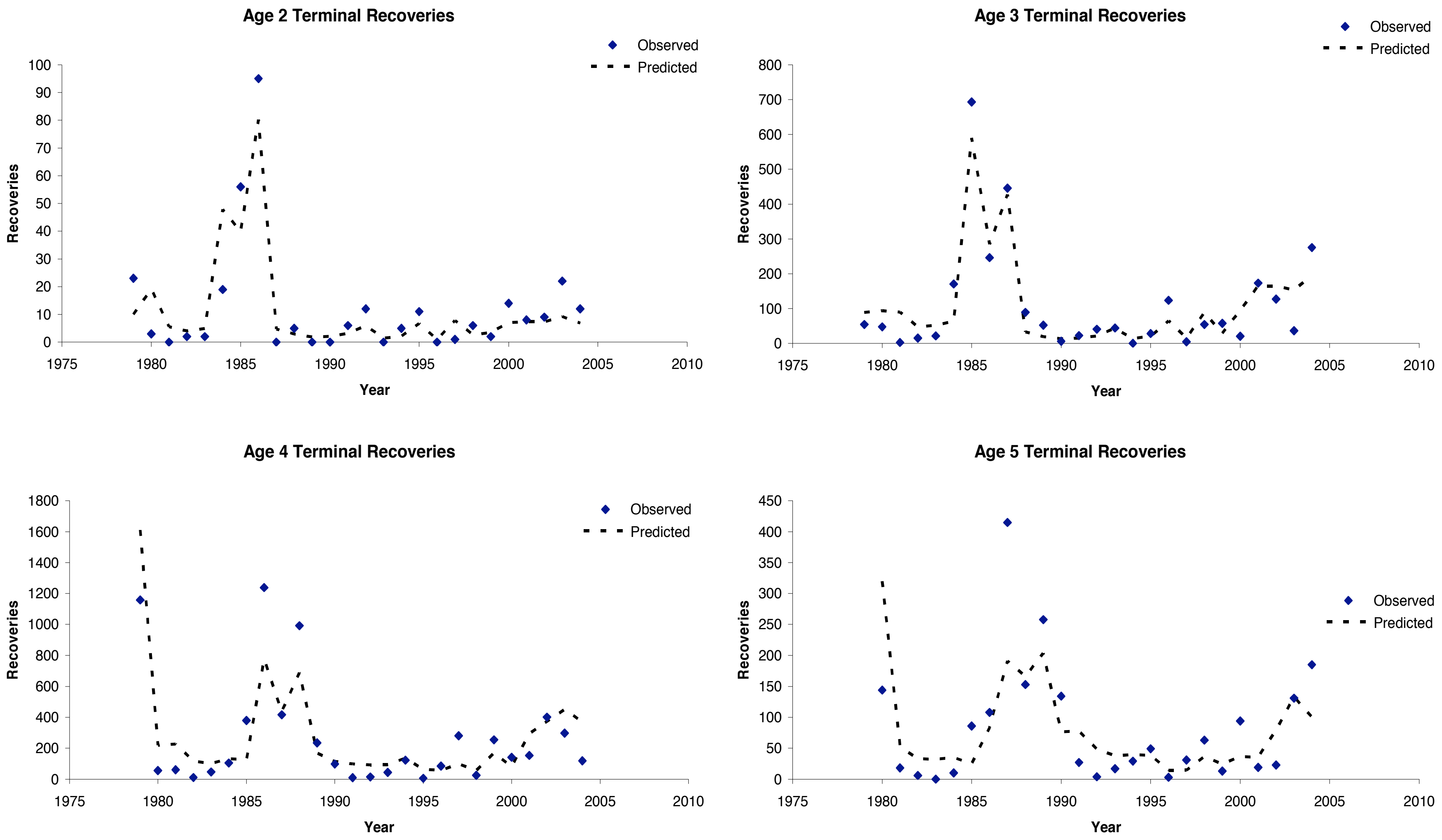


Figure 2.3: Model Versus Terminal Fisheries Fit for all ages

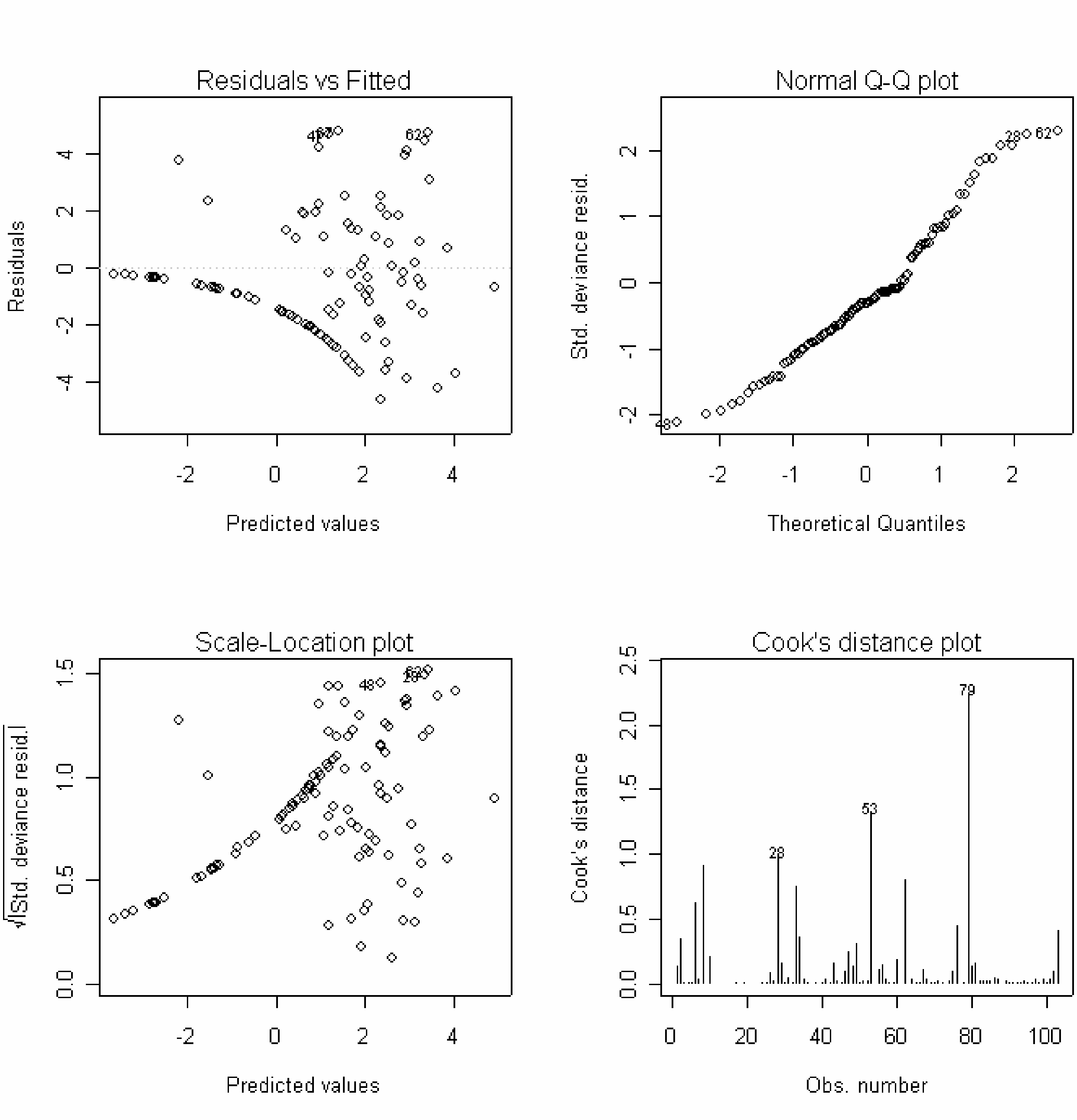


Figure 2.4: Residual Diagnostics for over all ages for Pre-terminal US ISBM fisheries

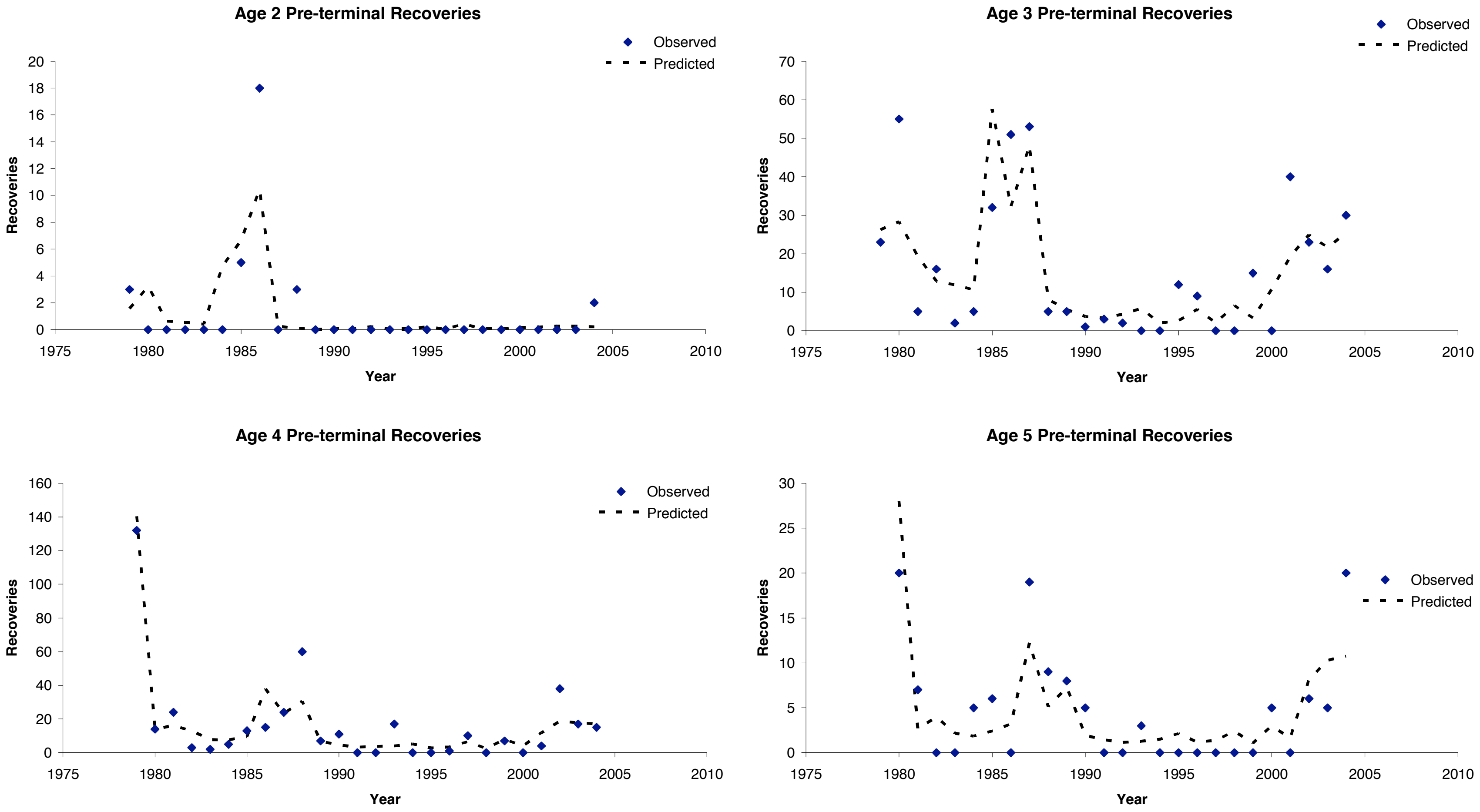


Figure 2.5: Model Versus Pre-terminal Fisheries Fit for all ages

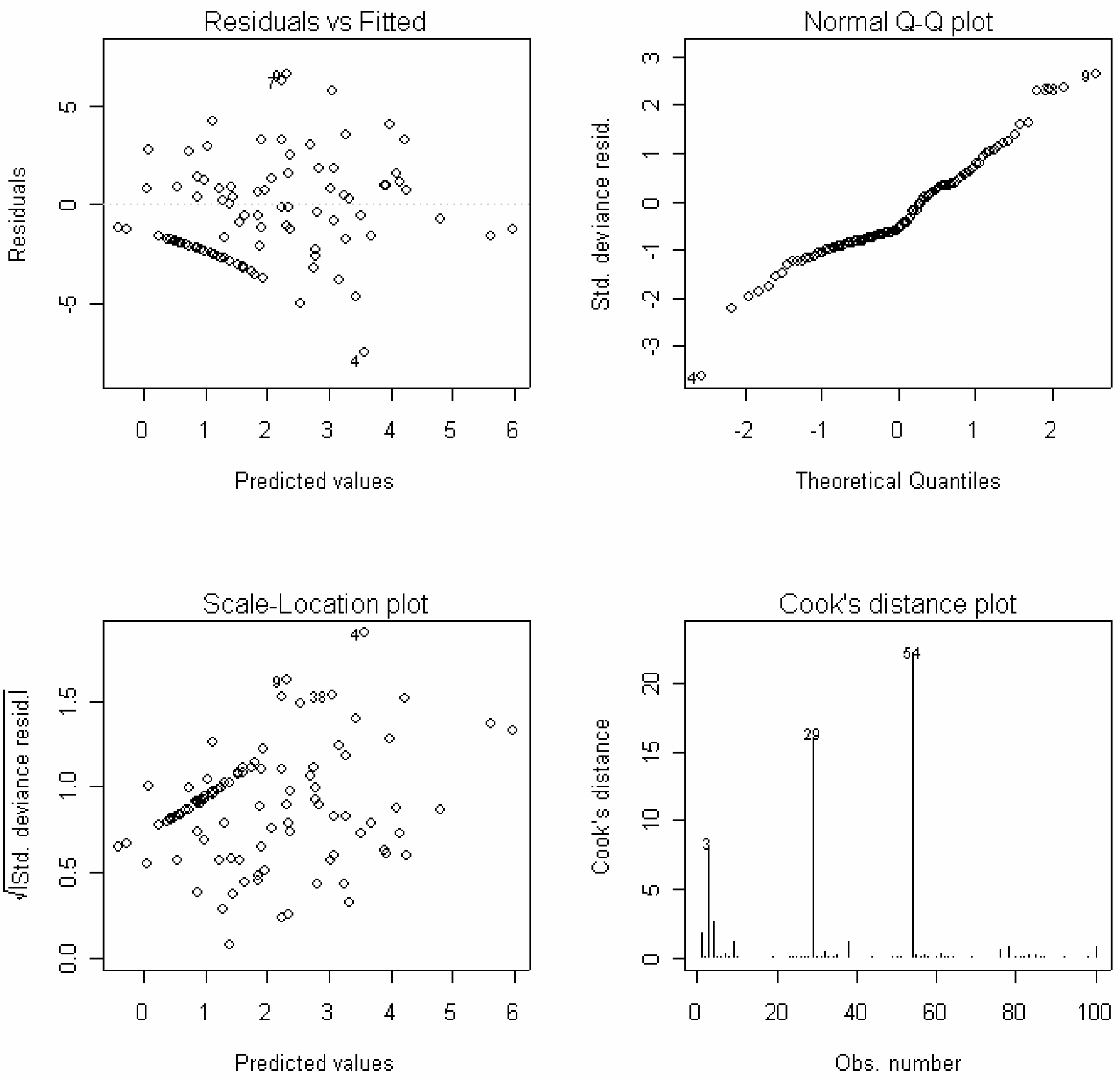


Figure 2.6: Residual Diagnostics over all ages for Canadian ISBM fisheries

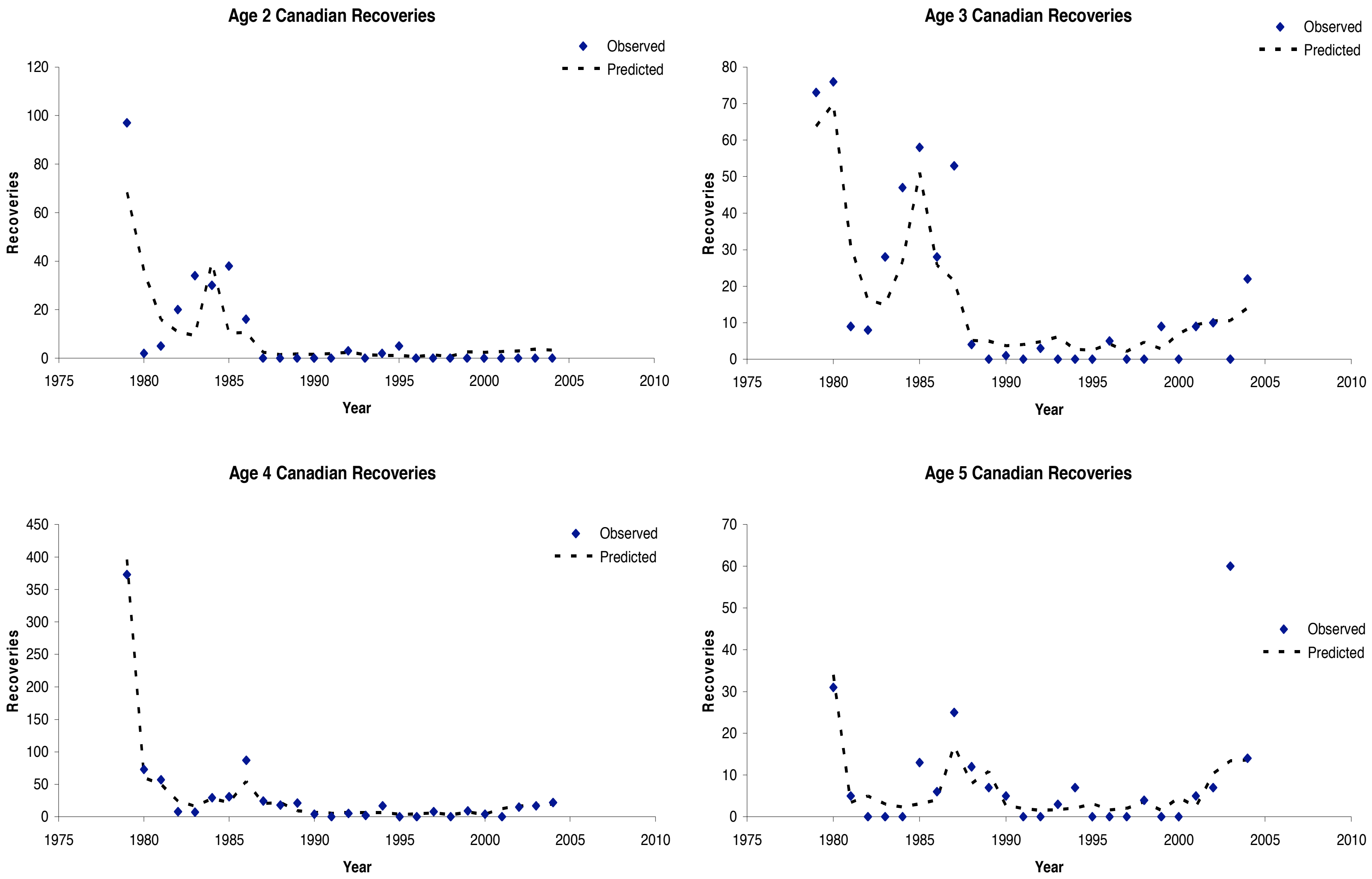


Figure 2.7: Model versus Canadian Fisheries Fit for all ages

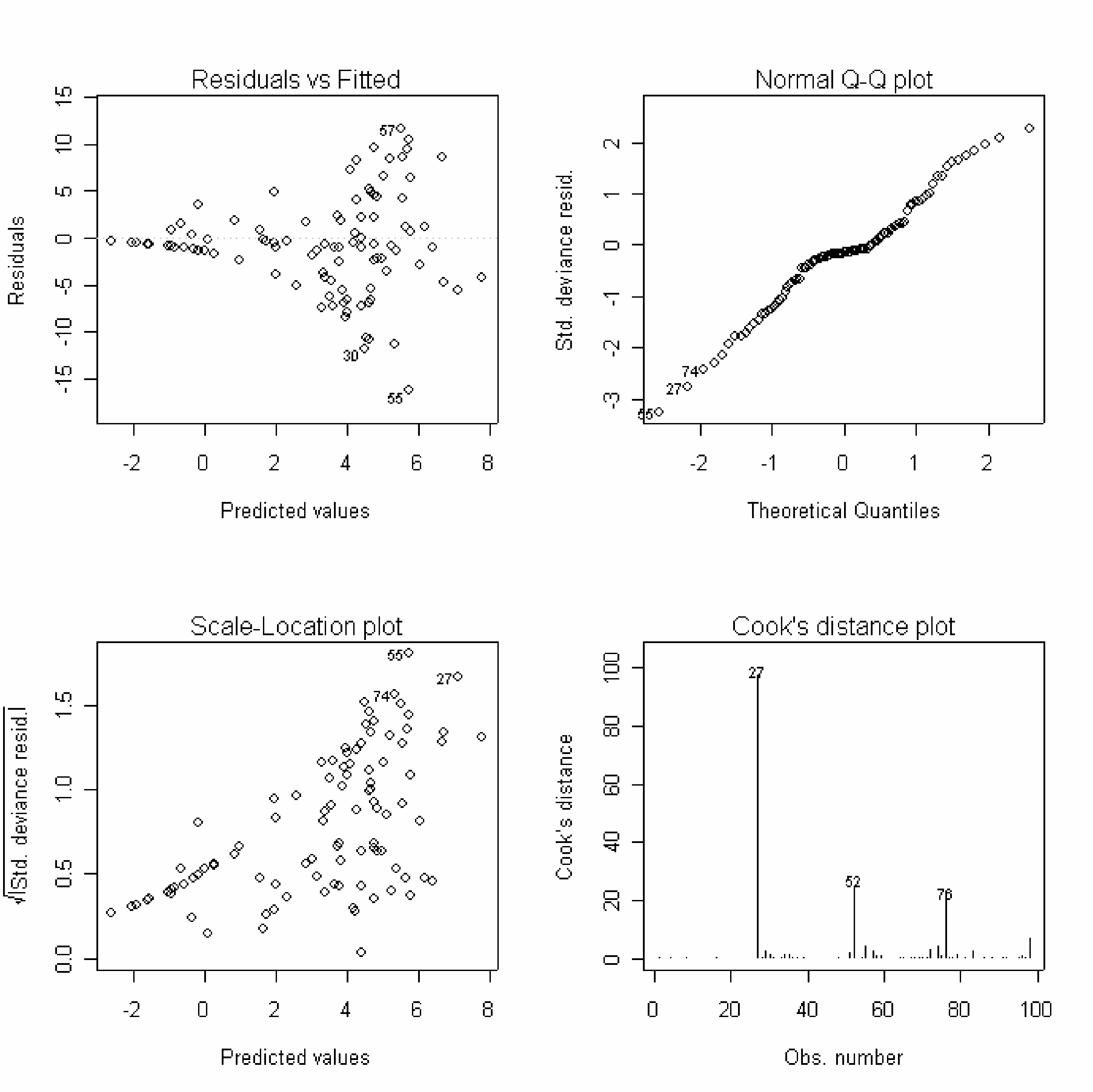
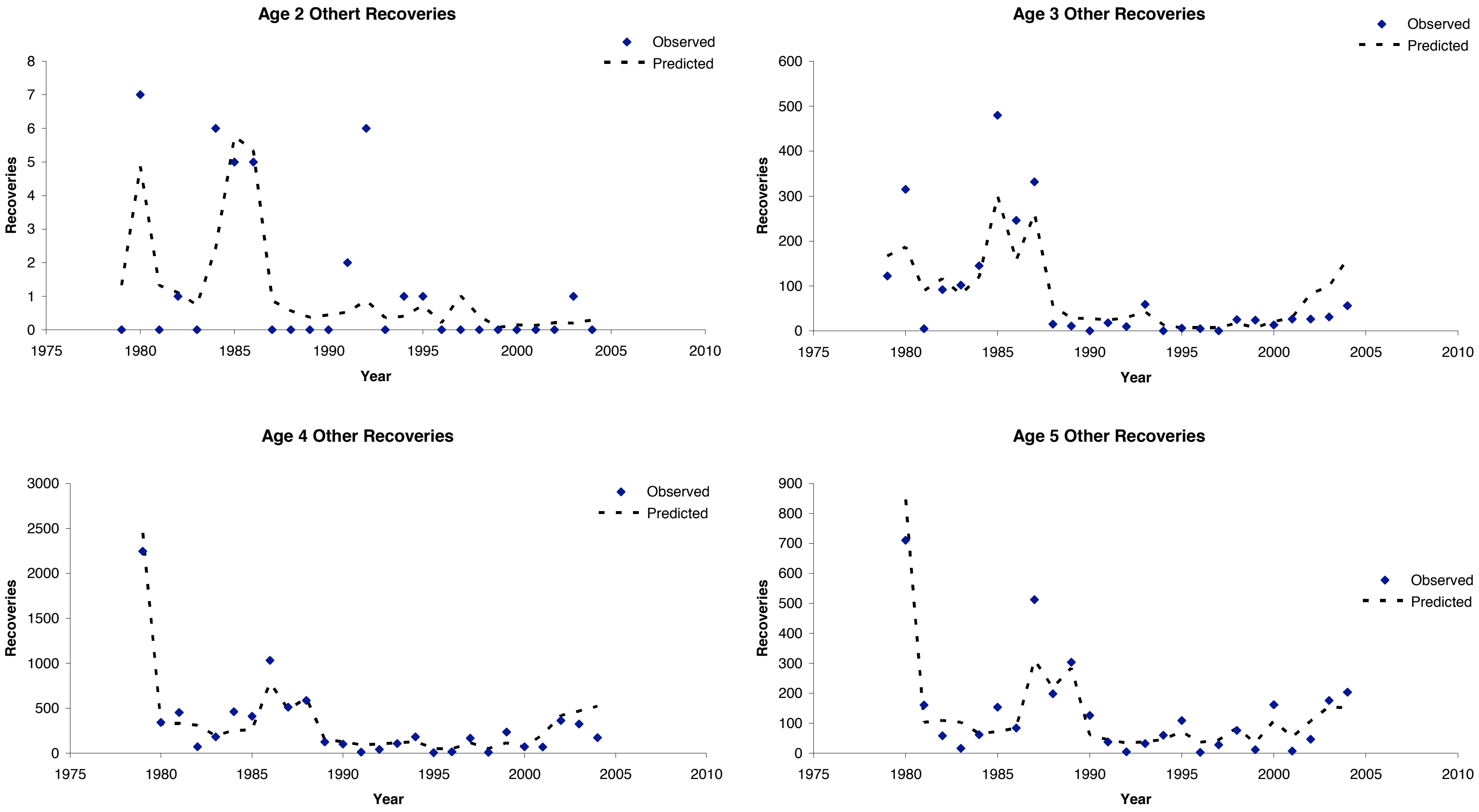


Figure 2.8: Residual Diagnostics over all ages for other fisheries


Age 2 Othert Recoveries

Age 3 Other Recoveries

Age 4 Other Recoveries

Age 5 Other Recoveries

Figure 2.7: Model versus other Fisheries Fit for all age