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Application of Bias-corrected Methods for Estimating Mortality in Mark-selective Fisheries to Coho FRAM

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Abstract

The current Fishery Regulation Assessment Models (FRAM) used in the Pacific Fishery Management Council's pre-season planning process to project mortalities during proposed coho and Chinook salmon fisheries underestimate the number of unmarked mortalities occurring in mark-selective fisheries and concurrent non-selective fisheries. This is a concern because all natural (wild) stocks are unmarked. The bias is caused by unmarked fish encountering fishing gear more than once in a modeled time step due to the required release of all unmarked fish and by the change in the unmarked-to-marked fish ratio resulting from the selective removal of marked salmon by the mark-selective fishery. The bias-correction methods proposed by Conrad and Yuen (2010) were applied to the 2009 and 2010 Coho FRAM final preseason runs to assess the amount of bias introduced by FRAM's computational structure and algorithms. The model was implemented with no catch and release (CNR) mortalities, no drop-off mortalities, and no mark misidentification errors to simplify the interpretation of results.

At current levels of exploitation for coho salmon, the bias in the FRAM estimate of the total exploitation rate of unmarked stocks is minimal. The mean and median differences by which FRAM underestimated the total exploitation rate for an unmarked stock were -0.003 in 2009 and -0.002 in 2010. For the 2009 and 2010 FRAM preseason runs, there was only a single instance where the difference between the FRAM estimate of the total exploitation rate for an unmarked stock and the bias-corrected estimates was ≥ -0.01 (-0.015 for Area 12A wild stock in 2009).

However, bias-correction is important when considering exploitation rate guidelines (limits) for coho stocks of concern. Although in the 2009 and 2010 preseason runs there were no instances where the bias-corrected estimate of total exploitation for a stock of concern exceeded its guideline (when CNR mortalities, drop-off mortalities, and mark misidentification errors were not included), the potential exists. For example, in 2009 the FRAM estimate for the total exploitation rate on the Upper Fraser River Wild stock (Thompson River coho with an exploitation rate guideline of 0.10 in southern US fisheries) of 0.094 was increased to 0.097 after bias-correction. If current FRAM projections of total exploitation rate for a stock of concern are very near a guideline, then there is a very real possibility that the bias-corrected estimate may exceed that guideline.

It is recommended that:

1. The bias-correction methodology is incorporated into Coho FRAM.
2. The implementation of bias-correction into FRAM be evaluated by comparing results from bias-corrected FRAM to bias-corrected results calculated outside the model as was done for this report.
3. The effects of adding in additional sources of mortality not included in the bias-correction evaluation to date (i.e., CNR mortality, drop-off mortality, and mark-recognition errors) be evaluated.
4. A process similar to that used to evaluate bias-correction in Coho FRAM be considered for Chinook FRAM.

Introduction

Mark-selective fisheries for coho salmon (*Oncorhynchus kisutch*) were introduced as a management tool in 1998 off the Washington coast (PFMC 1999a). Regulations for mark-selective fisheries permit the retention of legal-size coho which have had their adipose fin removed (marked) and require the release of all coho salmon with an adipose fin (unmarked) that are brought to the boat. The objective of mark-selective fisheries is to provide meaningful fisheries on abundant (marked) hatchery salmon while reducing the impact on wild salmon.

The Fishery Regulation Assessment Model (FRAM) is used by the Pacific Fishery Management Council (PFMC) during the pre-season planning process to project mortalities during proposed coho and Chinook salmon fisheries. FRAM is a single-pool, deterministic model that has discrete time steps that vary in length from one month to several months (PFMC 2008a). All fisheries during a time step are assumed to operate simultaneously on a single pool of fish. The pool of modeled fish consists of all stocks that have been caught historically in the fishery as estimated from coded-wire tag (CWT) recoveries (Nandor et al. 2010). Historical exploitation rates estimated from CWTs recovered during a base period when salmon abundances were relatively high and fisheries were widely distributed in both time and area are the basis for the FRAM predictions of fishery mortalities by stock (PSC 2005). Details for the methods and algorithms used in FRAM are presented in PFMC (2008b). PFMC (2007a and 2007b) provides a description of the base-period data used for the coho FRAM.

Prior to the implementation of mark-selective fisheries, a key FRAM assumption was that the exploitation rate for specific tagged salmon stocks (sometimes called indicator stocks) was representative of the exploitation rate for unmarked (typically wild) and marked stocks with similar life histories and ocean distributions. With the advent of mark-selective fisheries, the model was restructured so that the exploitation rates for these tagged indicator stocks were used to estimate the encounter rates in mark-selective fisheries for the unmarked stocks that they represent (PFMC 2008b). These encounter rates are used to produce stock-specific estimates of the number of encounters of unmarked fish in a mark-selective fishery which, combined with an estimate of the release-mortality rate, provide estimates of the mortalities due to the catch and release of unmarked salmon. In FRAM, the exploitation rate on the unmarked stock is a linear function of the exploitation rate on the tagged indicator stock used to represent the unmarked stock and the release-mortality rate. Since all marked fish encountered die, the exploitation rate of the tagged indicator stock is synonymous with the exploitation rate of the marked stock. Therefore, the exploitation rate calculation for an unmarked stock in FRAM can also be described as the exploitation rate of the marked stock component (ER_M) multiplied by the release mortality rate (δ).

Lawson and Sampson (1996) demonstrated that in a mark-selective fishery, the actual mortality rate of unmarked fish is an increasing function of the apparent harvest rate on the marked fish. This causes the total number of unmarked mortalities in mark-selective fisheries to be underestimated by models relying on the linear relationship between exploitation rate and release-mortality rate.

Conrad and Yuen (2010) described a bias correction method where the unbiased exploitation rate of the selectively exploited unmarked stock (ER_U) can be computed as an exponential function of the encounter rate of the corresponding marked stock component and the release mortality rate (δ):

$$ER_U = 1 - (1 - ER_M)^{\delta}. \quad [1]$$

FRAM's computational structure poses some challenges to applying the bias-corrected equation. As mentioned above, all fisheries occurring in a time step operate simultaneously on a single pool of fish.

Therefore, ER_M is computed as the sum of the marked exploitation rates[1] of all fisheries affecting a stock in a given time step. These fisheries can have a range of release mortality rates for the unmarked stock component. The bias-correction procedure used in this analysis is a modification of that proposed by Conrad and Yuen (2010) as suggested by Hagen-Breaux. Specifically, the total exploitation rate in all fisheries (both non-selective and mark-selective) for the marked component of the stock is used in equation 7 of Conrad and Yuen (2010) and a weighted release-mortality rate (equations 8 and 9) is calculated using 1.00 as the release-mortality rate for non-selective fisheries (NSF).

While previous work was focused on developing methods to compute unbiased mark-selective exploitation rates, the purpose of this report is to assess the magnitude of the bias arising from FRAM's computational structure and algorithms. Bias-correction methods for FRAM estimates of stock-specific exploitation rates on unmarked stocks were applied to the final 2009 and 2010 Coho FRAM preseason model runs (runs C0921 and C1016, respectively). The model was implemented with no CNR mortalities, no drop-off mortalities, and no mark misidentification errors. These adjustments were not included so that the bias resulting specifically from exploitation rates and release mortality rates could be assessed. FRAM's PopStat report was used as the source for stock cohort sizes and exploitation rates at each time step and within each time step ("After Natural Mortality" and "After Pre-terminal").

The years 2009 and 2010 were quite different in coho abundance forecasts thus providing an interesting contrast for comparing results. While the total predicted abundance of British Columbia and Puget Sound stocks was similar between these years, some individual stocks varied considerably. However, it is primarily Columbia River stocks that support the Oregon and Washington ocean mark-selective fisheries and for those stocks the predicted abundance of Columbia River and the US coastal stocks was much greater in 2009 than 2010. Total preseason abundance (sum of marked and unmarked fish) for Southern US stocks (no Canadian or Alaskan stocks) was predicted to be 2.81 million in 2009 compared to 1.87 million in 2010. Table 1 summarizes preseason abundance forecasts in each year.

Table 1. Summary of preseason abundance forecasts in the 2009 and 2010 FRAM preseason runs.

Year	Stock Group	Marked	Unmarked	Total
2009	Canadian and Southern US Stocks	1,723,617	2,108,322	3,831,939
	Southern US Only	1,648,857	1,156,796	2,805,653
	Columbia River, WA Coast, and OR Coast	1,275,357	782,904	2,058,261
2010	Canadian and Southern US Stocks	1,020,556	2,617,378	3,637,934
	Southern US Only	919,854	948,834	1,868,688
	Columbia River, WA Coast, and OR Coast	563,956	524,081	1,088,037

[1] For a marked or unmarked stock component, a time-step specific exploitation rate uses all fishery-related mortalities occurring in the time step (harvest plus release mortalities from mark-selective fisheries) for the numerator and the cohort abundance "After Natural Mortality" for the time step as the denominator (see Appendix A).

Methods

For each unmarked stock with a preseason abundance > 0, the time-step specific fishery exploitation rate (ER) for the marked component of the stock is the basis for the bias-corrected calculation of the exploitation rate for the unmarked stock. Since all marked fish encountered are assumed killed in a selective fishery, marked stock exploitation rates are a convenient surrogate for the encounter rates used by FRAM to compute the exploitation rates for the selectively exploited unmarked stock components. However, not all FRAM stocks have a marked stock equivalent. In these cases, the encounter rates can be computed using FRAM's base period exploitation rates and current year fisheries scalars:

$$ER_{M_{S,T}} = \sum_F (BPER_{S,F,T} \; x \; FishScalar_{F,T}) \qquad [2]$$

where,

BPER	=	base period exploitation rate for stock (*S*), fishery (*F*), and time step (*T*), and
FishScalar	=	fishery effort scalar for fishery and time step.

The procedure used to calculate the bias in the FRAM estimate of an exploitation rate for an unmarked stock is described in detail below.

Bias-correction Procedure:

Time Step 1
Step 1: Calculate a weighted release-mortality rate (δ_W) for the unmarked stock specific to the time step. As was demonstrated in Conrad and Yuen (2010), this can be calculated as the ratio of the FRAM ER for the unmarked stock ($\widetilde{ER}_U$)[2] to the FRAM ER for its marked stock component ($\widetilde{ER}_M$). For the time-step specific calculation,

$$\delta_W = \frac{\widetilde{ER}_U}{\widetilde{ER}_M} \qquad [3]$$

where both exploitation rates are time-step specific ERs based on cohort sizes in that time step after natural mortality. $\widetilde{ER}_M$ was extracted from a table containing time-step specific estimates of the exploitation rate for the marked component of the stock calculated from FRAM base period data as previously described. $\widetilde{ER}_U$ was calculated by first estimating unmarked fishery mortalities in the time step by subtracting PopStat's "After Preterminal" cohort size from the "After Natural Mortality" cohort size. This difference (the mortalities due to fisheries) was then divided by the "After Natural Mortality" cohort size.

Step 2: Calculate a bias-corrected, time-step specific, exploitation rate for the unmarked stock

$$\widehat{ER}_U = 1 - \left(1 - \sum \widetilde{ER}_M\right)^{\delta_W} . \qquad [4]$$

Step 3: Calculate the bias-corrected "After pre-terminal" fishery cohort abundance for the unmarked stock ($\widehat{N}_U$)

$$\widehat{N}_U = N_U \; x \left(1 - \widehat{ER}_U\right) \qquad [5]$$

where N_U is the cohort size after natural mortality for the time step.

[2] ~ is used to indicate a FRAM calculation and ^ to indicate a bias-corrected calculation.

Step 4: Calculate the bias-corrected number of fishery mortalities for the unmarked stock ($\widehat{D}_U$). This is simply the difference between the N_U and $\widehat{N}_U$,

$$\widehat{D}_U = N_U - \widehat{N}_U. \quad [6]$$

The relative bias ($\widehat{B}$) of the FRAM exploitation rate for the unmarked stock was calculated as:

$$\widehat{B} = \frac{\widetilde{ER}_U - \widehat{ER}_U}{\widehat{ER}_U} \, x \, 100\%. \quad [7]$$

A negative bias indicates that FRAM underestimated the true exploitation rate for the unmarked stock. The difference (Δ) between the two calculations of the ER (as defined in the numerator above) was examined, also.

Time Steps 2 through 5

The same four-step procedure is followed in subsequent time steps (2, 3, 4, and 5) with the following modification. In each new time step *i*, the new cohort size for the unmarked stock is the bias-corrected "After pre-terminal" fishery cohort abundance ($\widehat{N}_U$) calculated in the previous step (*i* - 1). This becomes the starting cohort size for the time step from which natural mortality is subsequently removed and then steps 1 through 4 implemented.

The bias-corrected total exploitation rate for an unmarked cohort is calculated as the sum of the bias-corrected fishery mortalities in each time step divided by those summed mortalities plus escapement (with the escapement re-estimated based on the bias-corrected mortalities). Appendix A provides an example of these calculations.

Summary Statistics:

Basic summary statistics for $\widehat{B}$ (relative bias of exploitation rate estimates) and Δ (absolute difference of exploitation rate estimates) were estimated for Washington, Oregon, and California origin stocks in each time step. Each stock was placed in a regional grouping so that differences by regions could be examined. Regions and number of unmarked stocks in each region are summarized in Table 2. Appendix B describes the specific stocks in each regional grouping. Box-and-whiskers plots were used to compare $\widehat{B}$ and Δ across time steps and regional groupings by time step.

Table 2. Definition of regions and number of unmarked stocks in each region.

Region Label	Description	Number of Stocks
NPS	North Puget Sound	13 (14[a])
MPS	Mid Puget Sound	9
SPS	South Puget Sound	8
HC	Hood Canal	7 (8[a])
SJF	Strait of Juan de Fuca	6
WAC	Washington Coast	15
CR	Columbia River	8
ORC	Oregon and California	9

[a] Stocks in 2010 model run.

Coho Stocks of Concern:

There are four coho "stocks of concern" in the PFMC management process which have ER guidelines that often constrain fisheries. The four stocks (or stock groups) are (with their ER guideline):

- Interior Fraser River Natural – 10 percent total ER in southern US fisheries,
- Lower Columbia River Natural (2009) – 20 percent total ER in marine and mainstem Columbia River fisheries), (2010) – 15 percent total ER in marine and mainstem Columbia River fisheries)
- Oregon Coastal Natural – 15 percent total ER, and
- Southern Oregon | Northern California Coast – 13 percent total ER.

The Interior Fraser River (also referred to as Thompson River) Natural ER is measured by a single unmarked stock (Upper Fraser River). Lower Columbia River Natural ER is measured by combining abundance and impacts for three stocks (Columbia River Wild Unmarked - Oregon, Columbia River Early Wild Unmarked – Washington, and Columbia River Late Wild - Washington). Oregon Coastal Natural (OCN) ER is also measured by combining abundance and impacts for three stocks (Oregon North Coastal Wild, Oregon North Mid Coastal Wild, and Oregon South Mid Coastal Wild). The southern Oregon|Northern California Coast ER is measured using the exploitation rate for the unmarked component of two hatchery stocks as surrogates (Oregon South Coast Hatchery and California North Coast Hatchery). The relative biases and differences between the exploitation rate estimates for these stocks, or stock aggregates, were examined separately so they could be compared to their ER guidelines. This was done on a cumulative FRAM ER basis (with a fixed denominator consisting of the sum of the catch over all time steps plus escapement) and on a time-step specific basis.

The Lower Columbia River Natural ER guideline is for marine fisheries combined with mainstem Columbia River fisheries. For this stock aggregate, only the marine impacts (including Buoy 10 sport) are calculated in the FRAM model. The total ER guideline for this stock is calculated outside the model and combines FRAM mortalities with impacts from mainstem Columbia River fisheries. Thus the total ER from FRAM fisheries is always well below the guideline to allow the mainstem Columbia River fisheries to occur. It is important to note that for this stock the ER guideline is always reached, as these river fisheries are structured to fish up to the total ER guideline.

Results

In 2009, there were 75 unmarked stocks for which bias-corrected exploitation rates were calculated[3]. In 2010, there were 77 unmarked stocks for which bias-corrected exploitation rates were calculated[3].

Relative Bias ($\hat{B}$):[4]

In both years, mean and median relative bias increased by time step through time step 3 (Tables 3 and 4)[5]. Mean and median bias in time step 4 was less than in time step 3 for both years. The mean and median biases for time step 5 estimates of exploitation rate were relatively small (less than 0.2%). Mean relative bias for the final FRAM estimate of the exploitation rate for the unmarked stocks was -0.90% in 2009 (median = -0.65%) and -0.68% in 2010 (median = -0.54%). As measured by the coefficient of variation (CV), there was considerable variability in relative bias across stocks within a time step during both years. The greatest observed relative bias for the total ER was -3.67% in 2009 and -2.11% in 2010. It is important to note that relative bias is expressed as a proportion of the bias-corrected ER estimate and is not the absolute difference between the biased and bias-corrected estimates.

Table 3. Summary statistics, by time step, for the relative bias of the FRAM exploitation rate estimates for unmarked coho stocks in the 2009 FRAM pre-season model run (N = 75).

Time Step	Mean	Standard Deviation	Coefficient of Variation	Median	Minimum	Maximum
1	-0.17%	0.177%	104%	-0.125%	-0.55%	0.00%
2	-2.30%	1.275%	55%	-2.022%	-6.32%	-0.78%
3	-3.40%	2.152%	63%	-2.614%	-9.72%	0.00%
4	-2.70%	3.005%	111%	-2.213%	-20.35%	0.16%
5	-0.01%	0.279%	559%	-0.001%	-0.66%	1.13%
Final	-0.90%	0.720%	80%	-0.649%	-3.67%	0.48%

Relative bias is expected to be negative whenever a stock has been subjected to a mark-selective fishery. The small positive relative biases present in some time steps are typically associated with stocks with very small exploitation rates in a time step, and|or very small cohort sizes, and are the result of rounding because the original FRAM estimates were rounded to the nearest whole fish compared to the bias-corrected estimates which did not round cohort numbers (i.e., fractional fish were carried forward in the computations).

[3] Canadian and Alaskan stocks are excluded from these summaries.
[4] Relative bias is expressed as a proportion of the bias-corrected ER estimate and is not the absolute difference between the biased and bias-corrected estimates.
[5] References to increases and decreases (or larger and smaller) are made without regard to the sign of $\hat{B}$ and Δ, e.g., -10% is considered larger than -5%.

Table 4. Summary statistics, by time step, for the relative bias of the FRAM exploitation rate estimates for unmarked coho stocks in the 2010 FRAM pre-season model run (N = 77).

Time Step	Mean	Standard Deviation	Coefficient of Variation	Median	Minimum	Maximum
1	-0.06%	0.104%	187%	-0.008%	-0.36%	0.17%
2	-1.31%	0.838%	64%	-1.214%	-4.49%	0.00%
3	-2.61%	1.612%	62%	-2.059%	-7.51%	0.00%
4	-1.74%	1.084%	62%	-1.571%	-6.06%	0.00%
5	-0.11%	0.336%	305%	-0.003%	-1.30%	0.78%
Final	-0.68%	0.537%	79%	-0.541%	-2.11%	0.74%

Figure 1 (top panel) summarizes the relative bias for the unmarked stocks by time step for each year. In 2009, several stocks had a relative bias exceeding -5% during time steps 2 (3 stocks), 3 (14 stocks), and 4 (4 stocks). There were only four estimates of relative bias exceeding -10%; all occurred during time step 4:

- Columbia River Early Hatchery Unmarked (-11.7%, bias-corrected time step ER = 0.073),
- Youngs Bay Hatchery Unmarked (-20.3%, bias-corrected time step ER = 0.112),
- Columbia River Wild Unmarked - Oregon (-11.7%, bias-corrected time step ER = 0.074), and
- Columbia River Early Wild Unmarked - Washington (-11.7%, bias-corrected time step ER = 0.073).

In 2010, there were only 9 stocks with a relative bias exceeding -5% during time step 3 and one stock with a bias exceeding -5% in time step 4 (Figure 1, bottom panel). In 2010, there were no stocks during any of the time steps with estimates of relative bias exceeding -10%.

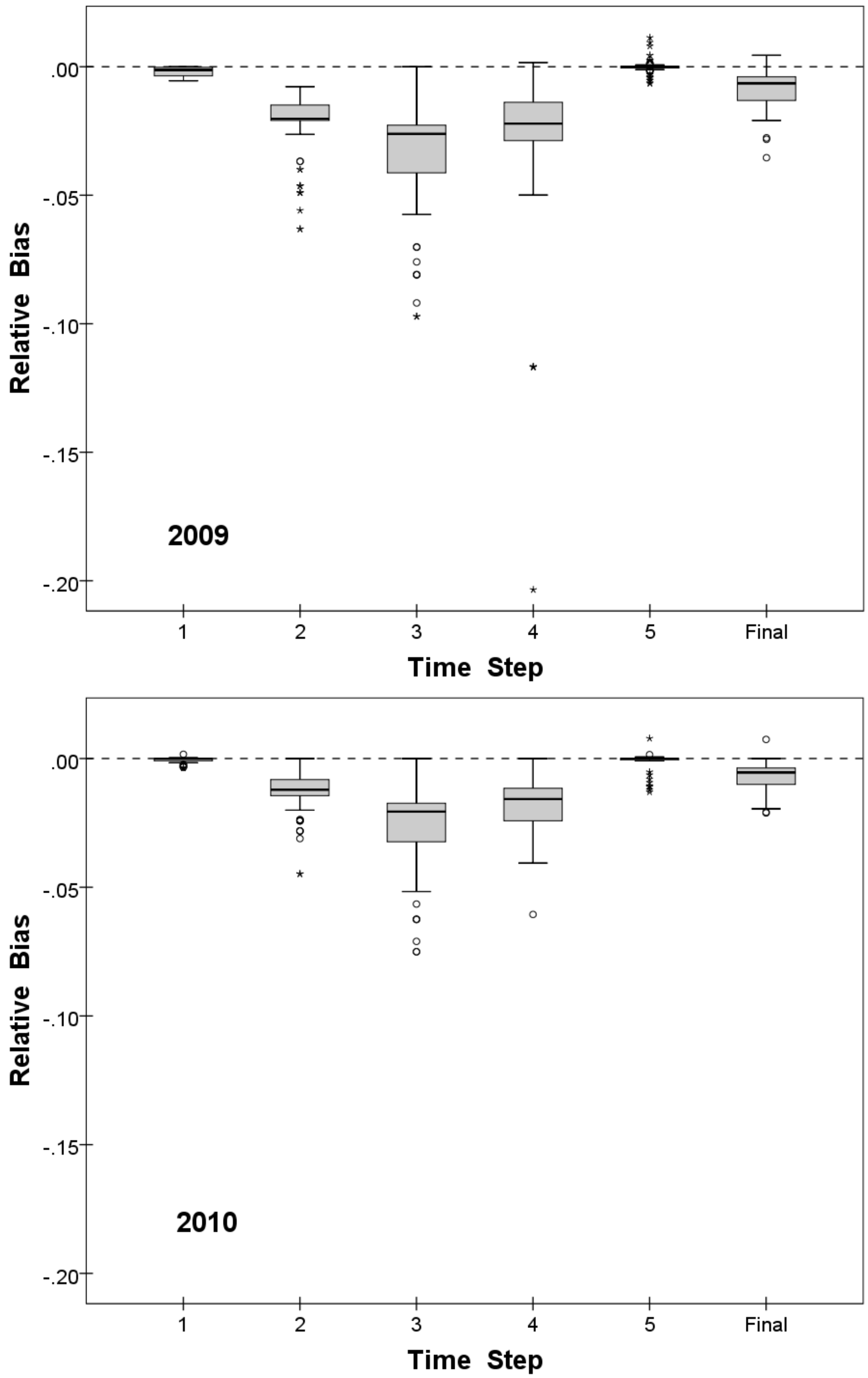

Figure 1. Box-and-whiskers plots summarizing the relative bias of the FRAM exploitation rates for unmarked coho stocks, by time step, for the final 2009 and 2010 preseason model runs with no CNR mortalities, no drop-off mortalities, and no mark misidentification errors.

Figures 2 and 3 compare the relative bias for the unmarked stocks by region in each time step for 2009 and 2010, respectively. Median relative bias was negative for all regions in all time steps in both years with the following exceptions:

- in 2009, median relative bias for the SJF region was 0 in time step 1 and positive in time step 5,
- in 2009, median relative bias for the COR and ORC regions was positive in time step 5,
- in 2010, median relative bias for the SPS, HC, and SJF regions was 0 in time step 1, and
- in 2010, median relative bias for the COR region was positive in time step 5.

As described earlier, these small positive relative biases are typically associated with stocks with very small exploitation rates in a time step, and|or very small cohort sizes, and are the result of rounding in the original FRAM model output. In both years, the COR (Columbia River) and ORC (Oregon-California) regions generally had larger negative relative biases compared to the other regions during time steps 1, 2, and 3.

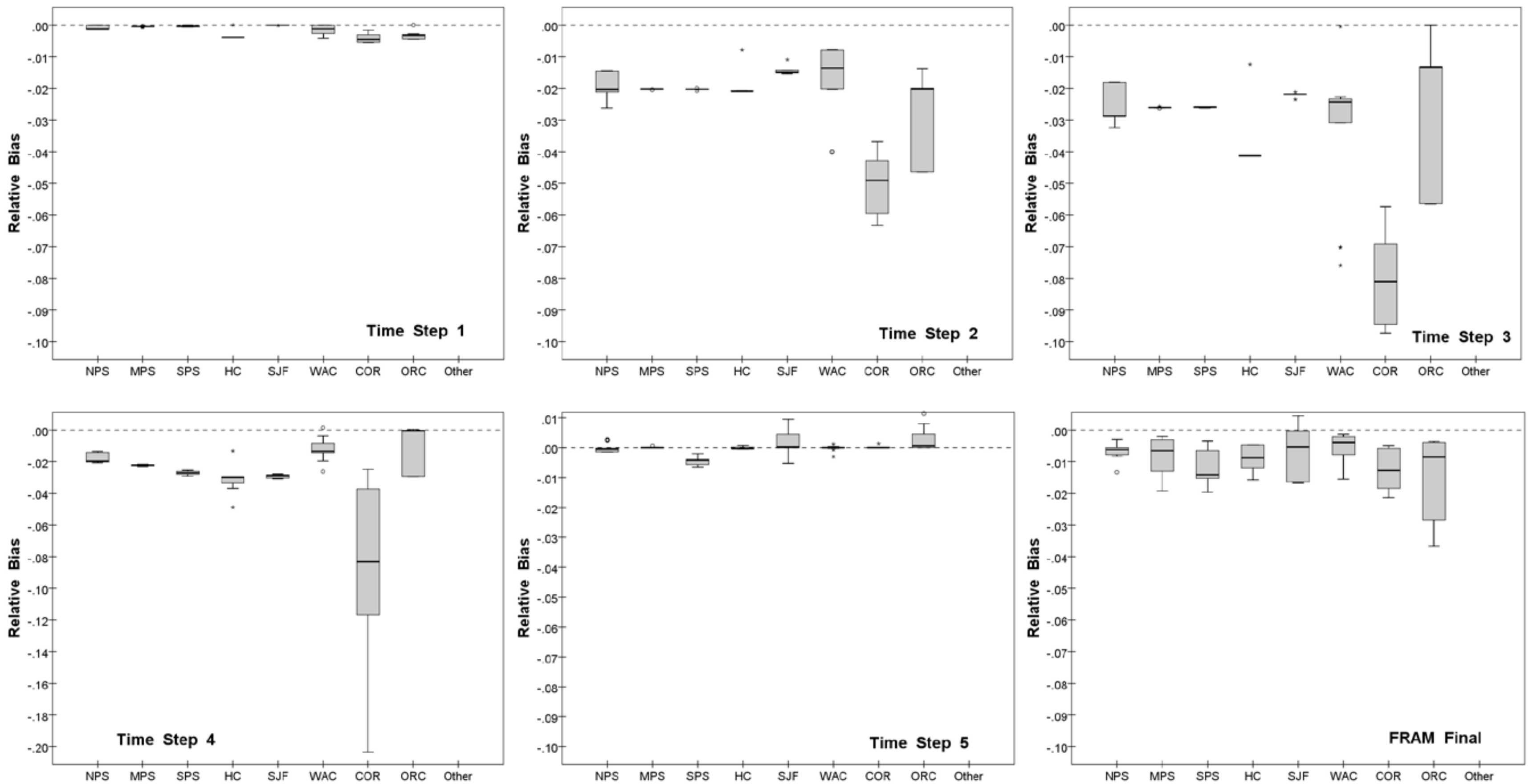

Figure 2. Box-and-whiskers plots comparing the relative bias of the FRAM exploitation rates for unmarked coho stocks, by region and time step, for the final 2009 preseason model run with no CNR mortalities, no drop-off mortalities, and no mark misidentification errors. Note that x-axis scale for time steps 4 and 5 is different from other time steps.

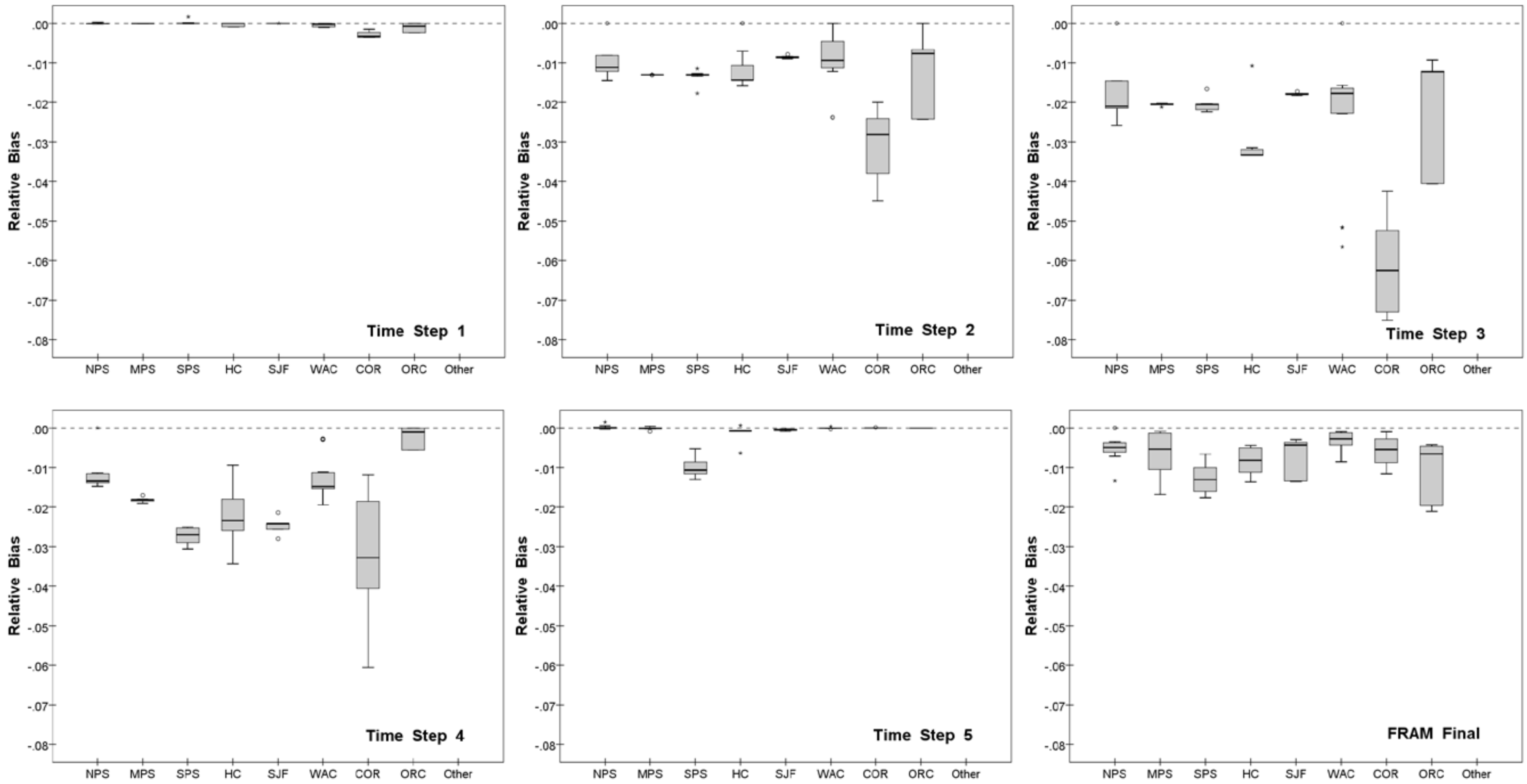

Figure 3. Box-and-whiskers plots comparing the relative bias of the FRAM exploitation rates for unmarked coho stocks, by region and time step, for the final 2010 preseason model run with no CNR mortalities, no drop-off mortalities, and no mark misidentification errors.

Difference (Δ):

In both years, the mean and median difference between the FRAM and bias-corrected estimates increased by time step through time step 4 (Tables 5 and 6). The mean and median differences for time step 5 estimates of exploitation rate were relatively small (less than 0.006). Mean difference for the final FRAM estimates of the exploitation rate for the unmarked stocks was -0.003 in 2009 (median = -0.0029) and -0.002 in 2010 (median = -0.002). As measured by the coefficient of variation (CV), there was considerable variability in the differences between the estimates across stocks within a time step.

Table 5. Summary statistics, by time step, for the difference between the FRAM and the bias-corrected estimates of exploitation rate for unmarked coho stocks in the 2009 FRAM pre-season model run (N = 75).

Time Step	Mean	Standard Deviation	Coefficient of Variation	Median	Minimum	Maximum
1	0.0000	0.0000	135%	0.0000	0.0000	0.0000
2	-0.0005	0.0004	72%	-0.0005	-0.0018	0.0000
3	-0.0012	0.0011	87%	-0.0011	-0.0048	0.0000
4	-0.0039	0.0063	163%	-0.0022	-0.0452	0.0001
5	-0.0002	0.0011	431%	0.0000	-0.0060	0.0022
Final	-0.0031	0.0025	82%	-0.0029	-0.0151	0.0013

Table 6. Summary statistics, by time step, for the difference between the FRAM and the bias-corrected estimates of exploitation rate for unmarked coho stocks in the 2010 FRAM pre-season model run (N = 77).

Time Step	Mean	Standard Deviation	Coefficient of Variation	Median	Minimum	Maximum
1	0.0000	0.0000	357%	0.0000	0.0000	0.0000
2	-0.0002	0.0002	80%	-0.0002	-0.0009	0.0000
3	-0.0008	0.0007	82%	-0.0006	-0.0029	0.0000
4	-0.0028	0.0041	146%	-0.0015	-0.0283	0.0000
5	-0.0005	0.0020	365%	0.0000	-0.0118	0.0021
Final	-0.0024	0.0022	94%	-0.0020	-0.0099	0.0027

Figure 4 summarizes the difference between the FRAM and the bias-corrected estimates of exploitation rate for unmarked stocks by time step for each year. Differences between the ERs exceeding -0.01 were rare. In 2009, differences greater than -0.01 occurred in:

- Quilcene Hatchery Unmarked (-0.022) in time step 4,
- Area 12A Natural Unmarked (-0.045) in time step 4,
- South Puget Sound Net Pens Unmarked (-0.014) in time step 4,
- Youngs Bay Hatchery Unmarked (-0.023) in time step 4, and
- Area 12A Natural Unmarked (-0.015) for the final ER.

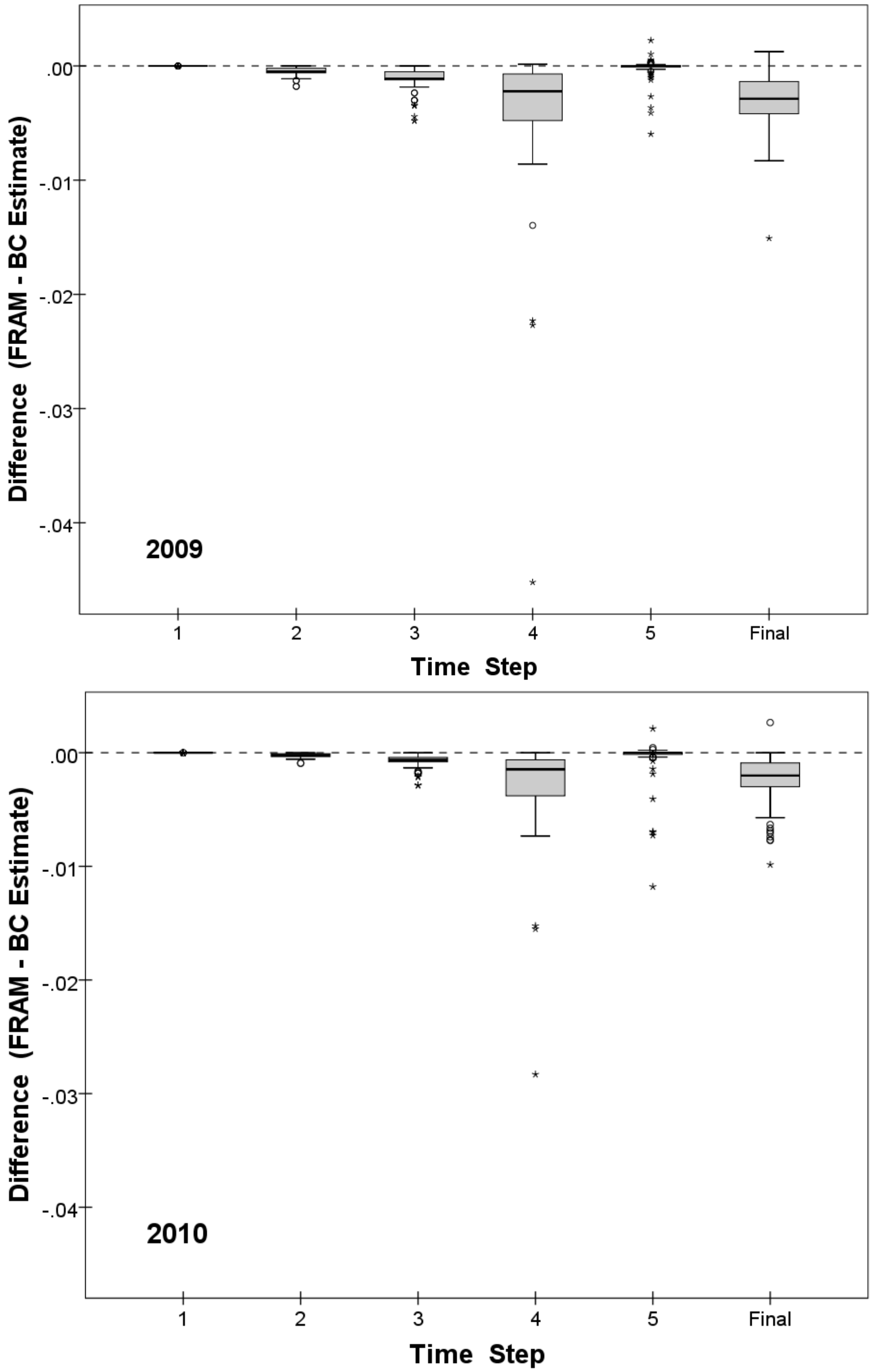

Figure 4. Box-and-whiskers plots summarizing the differences between the FRAM and bias-corrected (BC) exploitation rates of unmarked coho stocks, by time step, for the final 2009 and 2010 preseason model runs with no CNR mortalities, no drop-off mortalities, and no mark misidentification errors.

In 2010, there were differences greater than -0.01 for three of the same stocks:

- Quilcene Hatchery Unmarked (-0.015) in time step 4,
- Area 12A Natural Unmarked (-0.028) in time step 4,
- South Puget Sound Net Pens Unmarked (-0.016) in time step 4, and
- South Puget Sound Net Pens Unmarked (-0.012) in time step 5.

Stock sizes for the Quilcene Hatchery Unmarked, Area 12A Natural Unmarked, and South Puget Sound Net Pens Unmarked stocks are relatively small (less than 2,500 fish) while time-step specific ERs for time steps 4 and 5 are relatively high (generally > 0.50) for these stocks.

Figures 5 and 6 compare the difference between the FRAM and the bias-corrected estimates of exploitation rate for unmarked stocks by region in each time step for 2009 and 2010, respectively. Mean difference was negative for all regions in all time steps in both years with the following exceptions:

- in 2009, mean difference for the SJF region was 0 in time step 1,
- in 2009, mean differences for the MPS, SJF, COR, and ORC regions were positive in time step 5,
- in 2010, mean difference for the SPS and SJF regions was 0 in time step 1, and
- in 2010, mean difference for the NPS, WAC, and COR regions was positive in time step 5.

Similarly to relative bias, these small positive differences are due to rounding effects in the exploitation rate estimates for the original FRAM estimates (where cohort sizes were rounded to the nearest whole fish before calculation) compared to the bias-corrected estimates which did not use rounded cohort numbers. The COR region also had the largest negative differences compared to the other regions during time steps 2 and 3. The HC region had the largest differences in time step 4 and the SPS region had the largest differences in time step 5. The great majority of all differences were less than -0.005. Across all time periods and stocks, the difference between the FRAM ER estimate and bias-corrected estimate was greater than -0.005 in only 7 percent of the comparisons in 2009 and 5 percent in 2010.

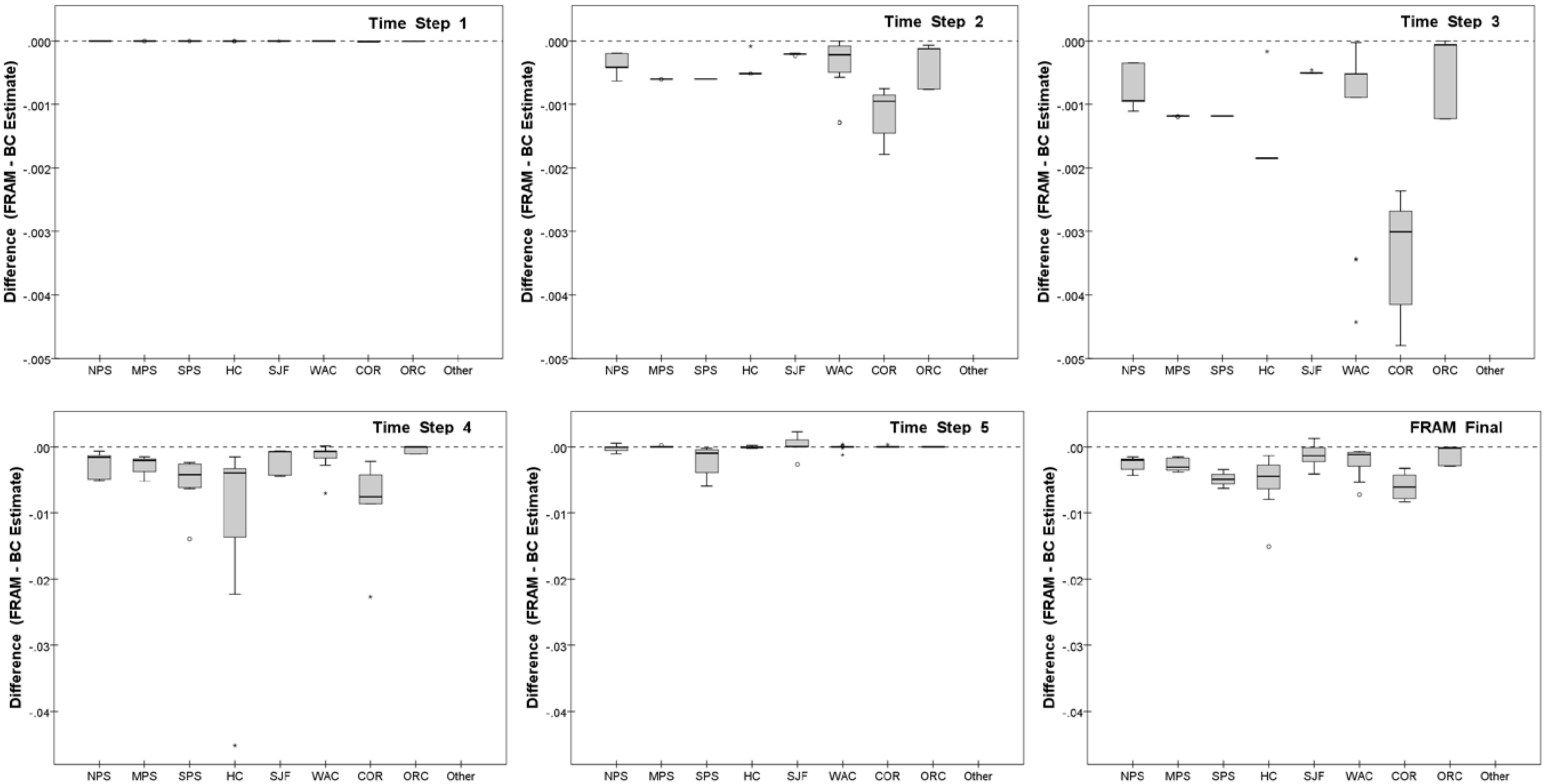

Figure 5. Box-and-whiskers plots comparing the differences between the FRAM and bias-corrected (BC) exploitation rates of unmarked coho stocks, by region and time step, for the final 2009 preseason model run with no CNR mortalities, no drop-off mortalities, and no mark misidentification errors. Note that x-axis scale for time steps 1 through 3 is different from the x-axis scale for time steps 5 though Final.

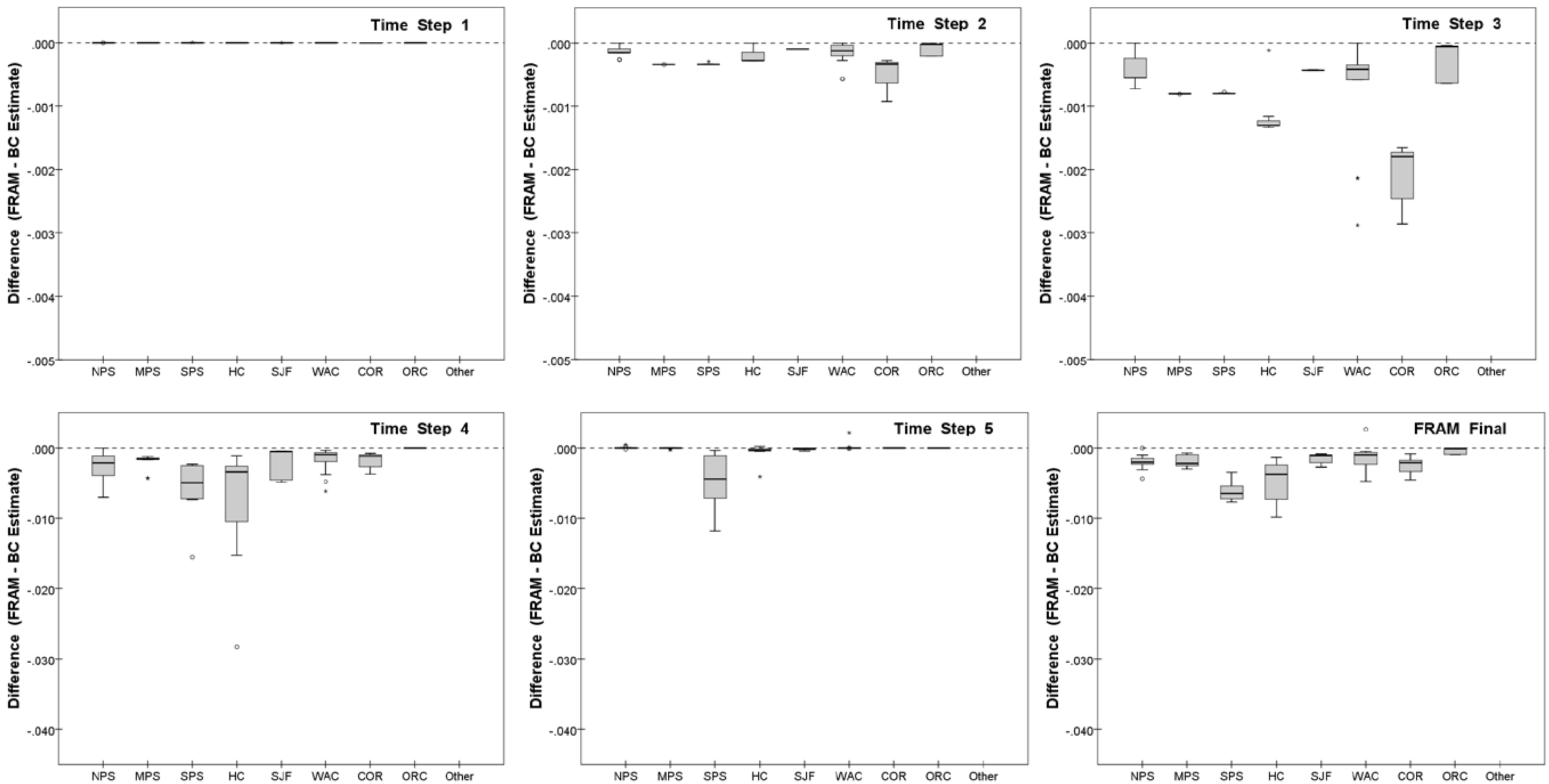

Figure 6. Box-and-whiskers plots comparing the differences between the FRAM and bias-corrected exploitation (BC) rates of unmarked coho stocks, by region and time step, for the final 2010 preseason model run with no CNR mortalities, no drop-off mortalities, and no mark misidentification errors. Note that x-axis scale for time steps 1 through 3 is different from the x-axis scale for time steps 5 though Final.

Coho Stocks of Concern:

The bias-corrected (BC) estimates of exploitation rate are compared to the FRAM estimates for the stocks (or stock aggregates) of concern below. These summaries compare the FRAM and bias-corrected estimates of exploitation rates on a cumulative basis over each time step with the ER calculated using a fixed denominator. It is important to remember that these ER estimates do not include the additional mortalities due to CNR, drop-off, or mark misidentification errors and are, therefore, underestimated. The time-step specific estimates of ER are compared in Appendix C.

Upper Fraser River Wild (Thompson R.) – 0.100 ER guideline: Although FRAM underestimated the final Upper Fraser River Wild exploitation rate by -2.7% (relative bias), the bias-corrected ER was still slightly below the 0.100 guideline in 2009. In 2010, relative bias and Δ were less than in 2009 in each time step.

Time Step	FRAM	BC	$\hat{B}$	Δ
2009				
1	0.000128	0.000128	-0.02%	0.000000
2	0.020981	0.021293	-1.46%	-0.000312
3	0.051145	0.052559	-2.69%	-0.001414
4	0.089089	0.091656	-2.80%	-0.002567
5	0.094190	0.096760	-2.66%	-0.002570
2010				
1	0.000136	0.000136	-0.01%	0.000000
2	0.013135	0.013251	-0.88%	-0.000116
3	0.039224	0.039997	-1.93%	-0.000773
4	0.075311	0.076795	-1.93%	-0.001484
5	0.079220	0.080700	-1.83%	-0.001480

Lower Columbia River Natural (three stock aggregate) – The ER guideline was 0.200 in 2009 and 0.150 in 2010: In 2009, FRAM underestimated the Lower Columbia River Natural exploitation rate through time step 4 by slightly more than 0.01. In 2010, relative bias and Δ were less than in 2009 in each time step. Although relative bias in time steps 3 and 4 was about 5 percent in 2010, the actual difference in exploitation rates (Δ) was small (less than 0.005). Because the fisheries in the mainstem of the Columbia River are structured to impact the stock up to the full ER guideline, any underestimate of the ER in the marine fisheries would result in the ER guideline being exceeded.

Time Step	FRAM	BC	$\hat{B}$	Δ
2009				
1	0.001857	0.001865	-0.45%	-0.000008
2	0.025876	0.027349	-5.38%	-0.001473
3	0.066029	0.071423	-7.55%	-0.005394
4	0.116625	0.126720	-7.97%	-0.010095
5				
2010				
1	0.001448	0.001452	-0.33%	-0.000005
2	0.016515	0.017081	-3.31%	-0.000566
3	0.046980	0.049730	-5.53%	-0.002750
4	0.074023	0.077678	-4.71%	-0.003655
5				

Guideline measured by combining FRAM impacts with mainstem Columbia River fishery impacts (most of which occur in time step 5) outside the model.

Oregon Coastal Natural (three stock aggregate) – 0.150 ER guideline: FRAM underestimated the final Oregon Coastal Natural exploitation rate by -3% (relative bias) but the bias-corrected ER was still well below the 0.150 guideline in 2009. In 2010, relative bias and Δ were less than in 2009 in each time step.

Time Step	FRAM	BC	$\hat{B}$	Δ
2009				
1	0.001659	0.001666	-0.43%	-0.000007
2	0.018230	0.019041	-4.26%	-0.000811
3	0.039174	0.041216	-4.95%	-0.002041
4	0.072247	0.075215	-3.95%	-0.002968
5	0.093427	0.096324	-3.01%	-0.002898
2010				
1	0.001005	0.001007	-0.24%	-0.000002
2	0.009970	0.010194	-2.20%	-0.000224
3	0.025545	0.026424	-3.33%	-0.000879
4	0.032135	0.033045	-2.75%	-0.000910
5	0.042577	0.043477	-2.07%	-0.000900

Southern Oregon | Northern California Coast (two stock aggregate) – 0.130 ER guideline: There were only very small differences between the FRAM and bias-corrected estimates for the Southern Oregon | Northern California Coast stock aggregate in 2009. In 2010, relative bias and Δ were less than in 2009 in each time step.

Time Step	FRAM	BC	$\hat{B}$	Δ
2009				
1	0.001232	0.001236	-0.33%	-0.000004
2	0.007336	0.007466	-1.74%	-0.000130
3	0.011817	0.012006	-1.58%	-0.000189
4	0.017249	0.017440	-1.09%	-0.000191
5	0.022737	0.022913	-0.77%	-0.000175
2010				
1	0.000372	0.000372	-0.09%	0.000000
2	0.002789	0.002808	-0.67%	-0.000019
3	0.006880	0.006950	-1.00%	-0.000070
4	0.007252	0.007322	-0.96%	-0.000070
5	0.012737	0.012807	-0.54%	-0.000070

Discussion

As was demonstrated in Conrad and Yuen (2010), the negative bias of the FRAM estimate of the exploitation rate for an unmarked stock when mark-selective fisheries occur during a time step (1) increases as the exploitation rate for the stock's marked component increases and (2) decreases as the weighted release mortality rate increases. The weighted release mortality rate is a gross indicator of the proportion of total exploitation occurring in mark-selective fisheries, e.g., a δ_W near 1.00 indicates that almost all of the exploitation is occurring in non-selective fisheries while a δ_W less than 0.20 indicates that most of the exploitation is occurring in mark-selective fisheries.

Figures 7 and 8 show the trend across time steps in the distributions of the exploitation rates for the marked stock components (upper panel) in comparison to the corresponding weighted release mortality rates (lower panel) for 2009 and 2010, respectively. Exploitation in time step 1 is minimal and therefore not a major contributor to bias despite the relatively low weighted release mortality rate. The exploitation rates then increase during time steps 2 and 3 which have weighted release mortality rates that are similar (usually between 30 percent to 40 percent). This explains the relatively large increase in bias during these time steps. While the exploitation rate for time step 4 is generally greater than that in time steps 2 and 3, its weighted release mortality rate increases greatly (to about 60 percent to 80 percent) which reduces bias relative to time steps 2 and 3. Although, the marked component exploitation rates generally continue to increase in time step 5, the weighted release mortality rate for the time step is nearly 100 percent for most stocks which results in a minimal contribution to overall bias for the last time step.

Generally, the relative biases for time steps 2, 3, and 4 were larger than the relative bias for the overall exploitation rate (Tables 3 and 4 and Figure 1). This is a result of 50 percent (on average) of the total exploitation rate for most unmarked stocks occurring in time step 5 where the majority of the fisheries are non-selective (Figures 7 and 8). Table 7 presents summary statistics for the proportion of the total FRAM exploitation rate that occurred in the largely non-selective time step 5 for the 2009 and 2010 FRAM runs.

Having a large proportion of the total exploitation on an unmarked stock occurring in non-selective fisheries during any time step reduces the overall (total) relative bias considerably. As a general rule, the overall bias will never exceed the greatest observed time step bias. Interestingly, when fisheries are modeled as rates, time steps are interchangeable. The overall exploitation rate and bias will be almost the same regardless of which time step selective and non-selective fisheries are modeled in; i.e., exploitation rates and release mortality rates for time steps 4 and 5 could be swapped and have very little effect on the overall catch, final exploitation rate, and bias.

Table 7. Summary statistics for the proportion of the total FRAM exploitation rate for the unmarked stock component occurring in time step 5, by year.

Year	Mean	Standard Deviation	Coefficient of Variation	Median	Minimum	Maximum
2009	49.8%	22.3%	45%	51.8%	0.0%	82.9%
2010	50.1%	24.5%	49%	50.1%	0.0%	91.6%

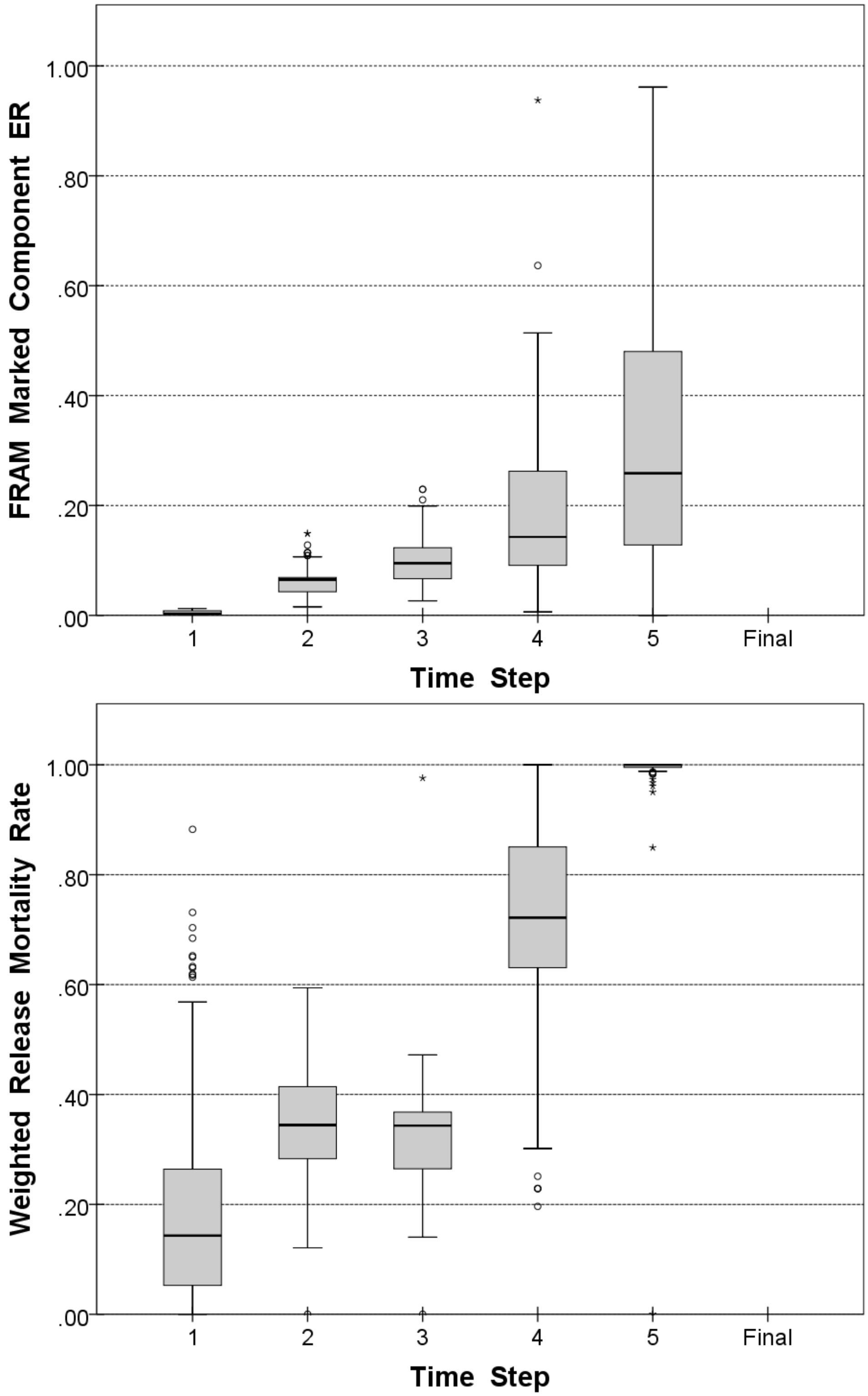

Figure 7. Box-and-whiskers plots summarizing FRAM exploitation rates for marked stock components (upper panel) and weighted release mortality rates (lower panel) by time step in 2009.

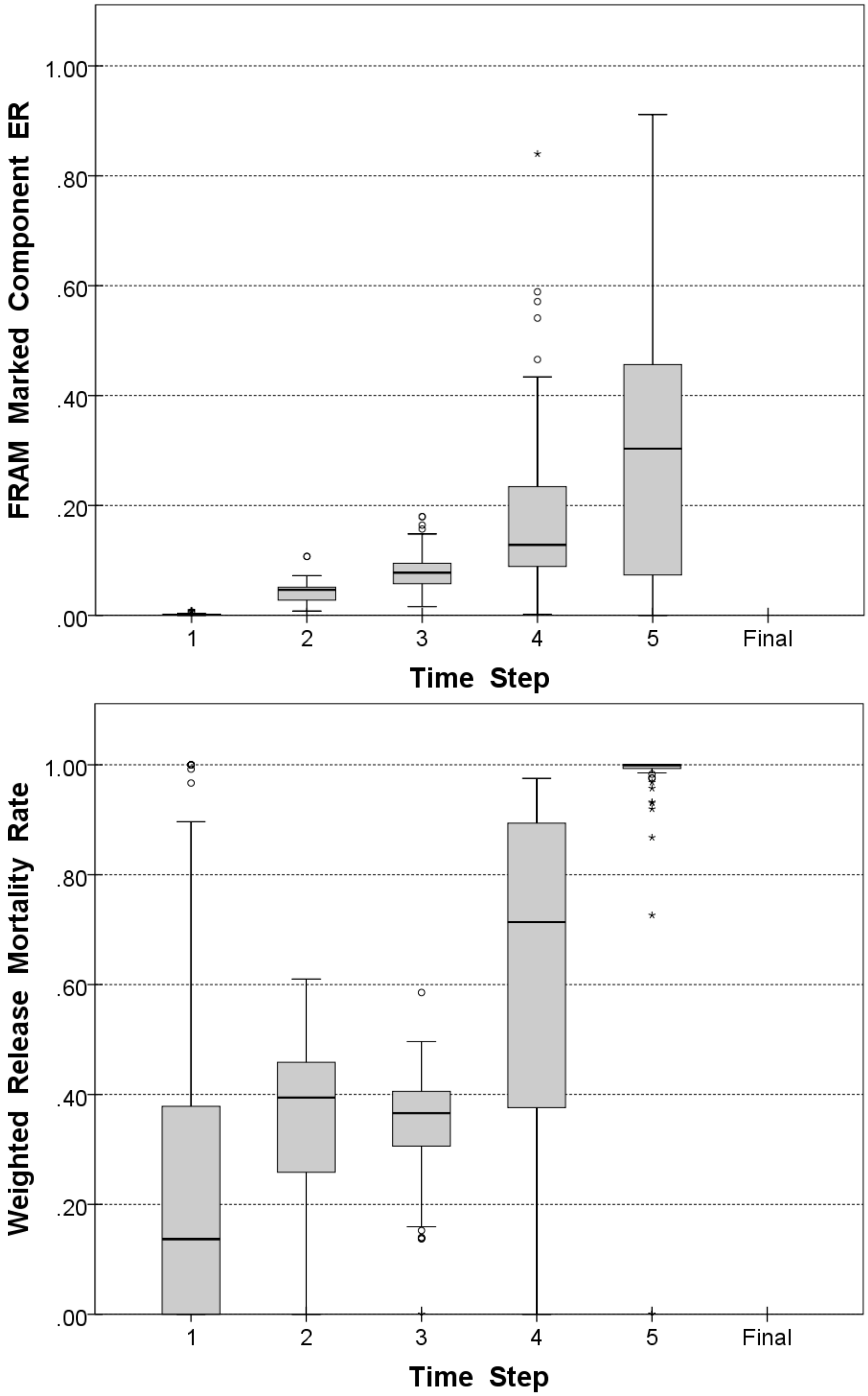

Figure 8. Box-and-whiskers plots summarizing FRAM exploitation rates for marked stock components (upper panel) and weighted release mortality rates (lower panel) by time step in 2010.

While the order of the time steps is not important, it does matter whether a non-selective fishery occurs in the same time step as a mark selective fishery or in a different time step. If the non-selective fishery occurs in the same time step as the mark-selective fishery, unmarked impacts will be underestimated by FRAM, thus adding to the existing bias. If the non-selective fishery occurs in a subsequent time step, FRAM will overestimate unmarked impacts, because it overestimates unmarked abundance, thus compensating for the already existing bias. Since the overall bias is a function of the mix of selective and non-selective fisheries occurring over all time steps, a simple rule as to what constitutes acceptable bias that is based on the size of the mark-selective fisheries alone will not work. The "30-10" rule, which recommended that the FRAM is "suitable for modeling mark-selective fisheries of low intensity, with 'low intensity' provisionally defined as those fisheries with fishery-specific exploitation rates on marked stocks of less than 10 percent and overall selective fishery exploitation rates of less than 30 percent" (PFMC 2011) can produce vastly different bias outcomes depending on the timing and magnitude of the non-selective fisheries.

There is not a similar compensating effect for the absolute differences between the FRAM and bias-corrected estimates of exploitation rates. For the differences between the estimates, the mean and median differences for time step 4 are only slightly greater than those for the FRAM final estimate (Tables 5 and 6 and Figure 4). The differences in exploitation rates in time steps 2 and 3 are generally less than those for the FRAM final estimate.

Therefore, we recommend focusing any evaluation of the impact of bias on the FRAM estimates of exploitation rates on the differences between the FRAM and bias-corrected estimates rather than relative bias. As has been demonstrated, what could be considered a large relative bias for the FRAM exploitation rate for an unmarked stock in one time step (say -10%) will be substantially reduced in another time step if the majority of the exploitation in the time step occurs in non-selective fisheries. Also, current guidelines for stocks of concern are usually expressed in terms of a total allowable exploitation rate.

Escapement Projections:

An important management consideration when using FRAM to develop management options for a fishing season is the projected escapement for certain stocks, especially wild stocks. Tables 8 and 9 summarize the relative percent differences[6] in projected escapement between the FRAM and bias-corrected methods for 2009 and 2010, respectively. Across all unmarked stocks, FRAM overestimated escapement (relative to the bias-corrected estimate) by about 2 percent in 2009 and 1 percent in 2010, on average. The largest relative differences between the escapement projections occurred for the same two stocks in both years. The escapement for the Area 12 Wild (unmarked) stock was 62 percent greater than the bias-corrected projection in 2009 (53 fish compared to 33 fish) and 17 percent greater in 2010. The escapement for the South Puget Sound Net Pen (unmarked) stock was 18 percent greater than the bias-corrected projection in 2009 and 17 percent greater in 2010. Relative percent differences in escapement projections for all other stocks were less than 6 percent.

In terms of number of fish, the largest differences between the escapement projections were 711 fish for the Columbia River Hatchery Unmarked stock in 2009 and 214 fish for the Snohomish Wild Unmarked stock in 2010. In both years, most of the larger differences in numbers of fish for escapement projections occurred in the Columbia River region (Figure 9). Across all unmarked stocks, FRAM overestimated escapement (relative to the bias-corrected estimate) by about 43 fish in 2009 and 17 fish in 2010, on average.

[6] Relative percent difference = (FRAM projected escapement – bias-corrected projected escapement)/bias-corrected projected escapement.

Table 8. Summary statistics, by region, for the relative percent difference between the FRAM and the bias-corrected estimates of escapement for unmarked coho stocks in the 2009 FRAM pre-season model run.

Regional Group	Mean	Standard Deviation	Coefficient of Variation	Median	Minimum	Maximum
NPS	0.6%	0.37%	65%	0.4%	0.2%	1.2%
MPS	0.5%	0.20%	36%	0.5%	0.3%	0.9%
SPS	3.2%	6.11%	189%	1.1%	0.5%	18.3%
HC	10.1%	22.81%	226%	0.7%	0.3%	61.6%
SJF	0.2%	0.31%	170%	0.1%	-0.3%	0.7%
WAC	0.6%	1.10%	174%	0.2%	0.1%	4.4%
COR	1.4%	0.68%	49%	1.3%	0.9%	3.0%
ORC	0.1%	0.21%	246%	0.0%	-0.4%	0.3%
Total	1.8%	7.35%	419%	0.5%	-0.4%	61.6%

Table 9. Summary statistics, by region, for the relative percent difference between the FRAM and the bias-corrected estimates of escapement for unmarked coho stocks in the 2010 FRAM pre-season model run.

Regional Group	Mean	Standard Deviation	Coefficient of Variation	Median	Minimum	Maximum
NPS	-0.6%	3.62%	620%	0.3%	-13.0%	1.5%
MPS	0.4%	0.25%	65%	0.3%	-0.1%	0.7%
SPS	3.3%	5.53%	166%	1.4%	0.2%	16.8%
HC	3.2%	5.54%	175%	0.6%	0.4%	16.5%
SJF	0.1%	0.33%	221%	0.1%	-0.3%	0.6%
WAC	-0.1%	1.91%	1293%	0.2%	-6.9%	1.4%
COR	0.5%	0.17%	35%	0.4%	0.3%	0.7%
ORC	0.0%	0.17%	533%	0.0%	-0.3%	0.3%
Total	0.7%	3.24%	498%	0.3%	-13.0%	16.8%

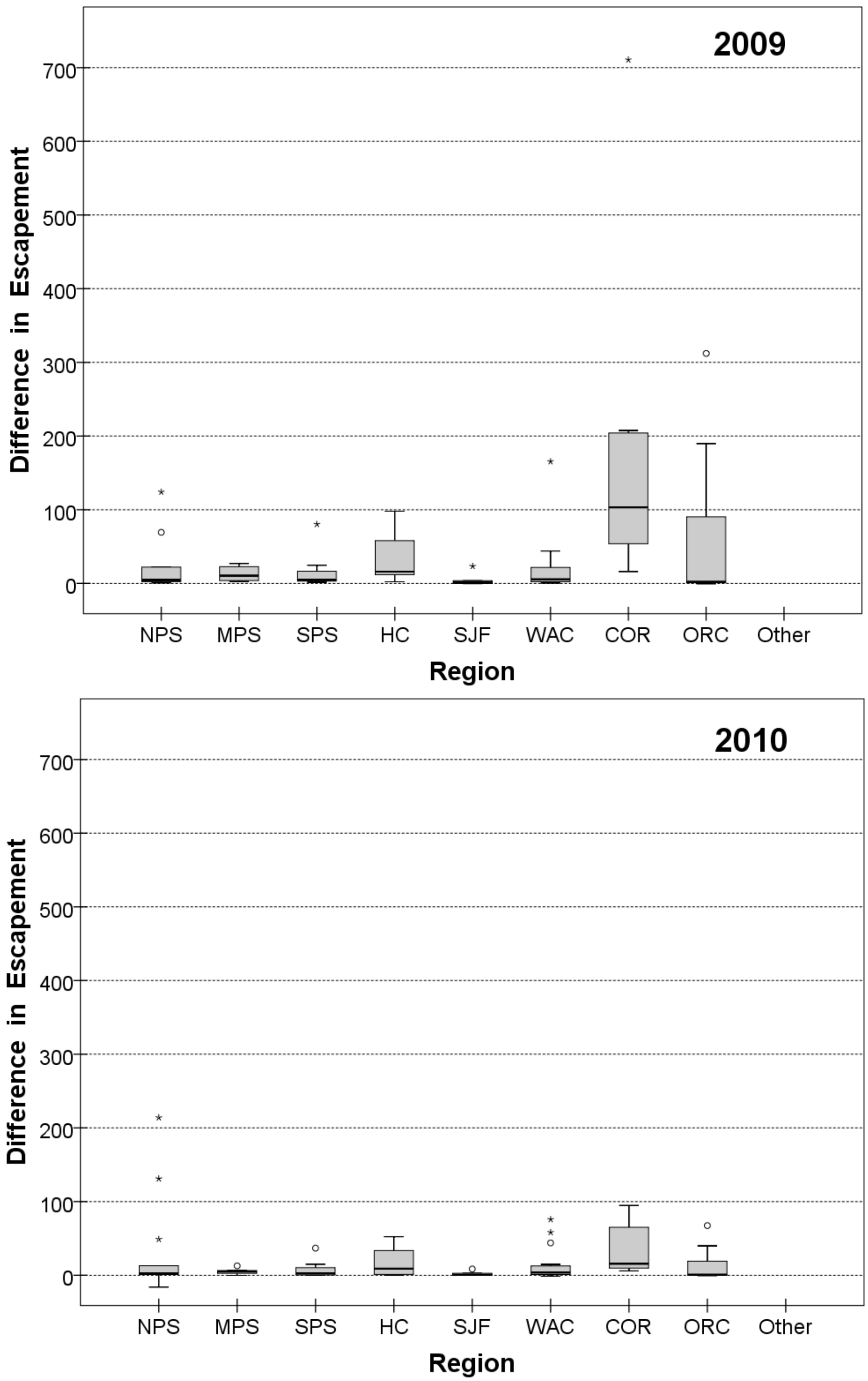

Figure 9. Box-and-whiskers plots summarizing the differences in escapement estimates between the FRAM and bias-corrected methods for unmarked coho stocks, by regional group, for the final 2009 and 2010 preseason model runs with no CNR mortalities, no drop-off mortalities, and no mark misidentification errors.

Conclusions

At current levels of exploitation for coho salmon, the bias in the FRAM estimate of the total exploitation rate of unmarked stocks is minimal. The mean and median differences by which FRAM underestimated the total exploitation rate for an unmarked stock were -0.003 in 2009 and -0.002 in 2010. For the 2009 and 2010 FRAM preseason runs, there was only a single instance where the difference between the FRAM estimate of the total exploitation rate for an unmarked stock and the bias-corrected estimates was ≥ -0.01 (-0.015 for Area 12A wild stock in 2009).

However, bias-correction is important when considering exploitation rate guidelines (limits) for coho stocks of concern. Although in the 2009 and 2010 preseason runs there were no instances where the bias-corrected estimate of total exploitation for a stock of concern exceeded its guideline, the potential exists. For example, in 2009 the FRAM estimate for the total exploitation rate on the Upper Fraser River Wild stock (Thompson River coho with an exploitation rate guideline of 0.10 in southern US fisheries) of 0.094 was increased to 0.097 after bias-correction. If FRAM projections of total exploitation rate for a stock of concern are very near a guideline, then there is a very real possibility that the bias-corrected estimate may exceed that guideline.

Also, for the case where a portion of the exploitation rate for a stock is modeled outside of FRAM (as is done for the Lower Columbia River Natural stock aggregate), the underestimate of the exploitation rate for that portion of the impacts occurring in FRAM modeled fisheries must be considered. Because impacts outside the FRAM model are typically projected to be the maximum allowable under the guideline, the guideline will always be exceeded if the bias in the FRAM estimates is not considered.

The current fishery exploitation rate pattern for coho salmon, where stock-specific exploitation rates in the last time step (time step 5) are generally large relative to the ERs in earlier time steps and fisheries in the last time step are almost exclusively non-selective, is largely responsible for keeping the bias in the total FRAM ER introduced by mark-selective fisheries in earlier time steps small. The current version of FRAM usually overestimates the fishery-related mortalities in the last time step, relative to the bias-corrected estimates, because;

- FRAM currently tends to overestimate the cohort size of an unmarked stock entering time step 5 relative to the bias-corrected estimates because it has underestimated fishery mortalities in earlier time steps, and
- Fisheries in the last time step are almost entirely non-selective so the same stock-specific ER is being applied to the starting cohort abundance in time step 5 by both the current FRAM version and the bias-corrected methods.

These additional mortalities in time step 5 in current FRAM then reduce the underestimation of mortalities in earlier time steps and typically result in a relatively small overall bias for the total stock-specific ER estimate.

Recommendations

We recommend that:

1. The bias-correction methodology is incorporated into Coho FRAM.
2. The implementation of bias-correction into FRAM be evaluated by comparing results from bias-corrected FRAM to bias-corrected results calculated outside the model as was done for this report.
3. The effects of adding in additional sources of mortality not included in the bias-correction evaluation to date (i.e., CNR mortality, drop-off mortality, and mark-recognition errors) be evaluated.
4. A process similar to that used to evaluate bias-correction in Coho FRAM be considered for Chinook FRAM.

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Appendix A

Bias-correction calculation example using FRAM PopStat report.

	U-colreh	M-colreh	Derived From	Weighted Release Mortality δ	Derived From	Bias-corrected U-croreh	Derived From
Time Step 1							
Starting Cohort	120,659	516,048	PopStat Report			120,659	PopStat Report
After Nat. Mort	106,481	455,410	PopStat Report			106,481	PopStat Report
After PreTerm	106,310	449,766	PopStat Report			106,309	After NatMort*(1-ER_UM)
Catch	171	5,644	After NatMort - After PreTerm			172	After NatMort - After PreTerm
FRAM TS ER	0.00161	0.01239	Catch/After NatMort	0.12958	(FRAM TS ER_UM)/ (FRAM TS ER_M)	0.00161	ER_UM: 1-(1-ER_M)^δ
Time Step 2							
Starting Cohort	106,310	449,766	PopStat Report			106,309	After PreTerm from previous step
After Nat. Mort	104,118	440,493	PopStat Report			104,117	Starting Cohort * (1- NatMort)
After PreTerm	102,200	390,246	PopStat Report			102,100	After NatMort*(1-ER_UM)
Catch	1,918	50,247	After NatMort - After PreTerm			2,017	After NatMort - After PreTerm
FRAM TS ER	0.01842	0.11407	Catch/After NatMort	0.16149		0.01937	ER_UM: 1-(1-ER_M)^δ
Time Step 3							
Starting Cohort	102,200	390,246	PopStat Report			102,100	After PreTerm from previous step
After Nat. Mort	100,093	382,200	PopStat Report			99,995	Starting Cohort * (1- NatMort)
After PreTerm	96,673	309,807	PopStat Report			96,278	After NatMort*(1-ER_UM)
Catch	3,420	72,393	After NatMort - After PreTerm			3,717	After NatMort - After PreTerm
FRAM TS ER	0.03417	0.18941	Catch/After NatMort	0.18039		0.03717	ER_UM: 1-(1-ER_M)^δ

	U-colreh	M-colreh	Derived From	Weighted Release Mortality δ	Derived From	Bias-corrected U-croreh	Derived From
Time Step 4							
Starting Cohort	96,673	309,807	PopStat Report			96,278	After PreTerm from previous step
After Nat. Mort	94,680	303,420	PopStat Report			94,293	Starting Cohort * (1- NatMort)
After PreTerm	88,546	217,498	PopStat Report			87,378	After NatMort*(1-ER_UM)
Catch	6,134	85,922	After NatMort - After PreTerm			6,915	After NatMort - After PreTerm
FRAM TS ER	0.06479	0.28318	Catch/After NatMort	0.22878		0.07334	ER_UM: 1-(1-ER_M)^δ
Columbia River base period fisheries used for this time step 5 example. Actual time step 5 exploitation rate calculations are currently not modeled in FRAM .							
Time Step 5							
Starting Cohort	88,546	217,498	PopStat Report			87,378	After PreTerm from previous step
After Nat. Mort	86,721	213,014	PopStat Report			85,577	Starting Cohort * (1- NatMort)
After PreTerm	86,721	213,014	PopStat Report			85,577	Same as After Nat Mort
Mature Cohort	86,721	213,014	PopStat Report			85,577	Same as After Nat Mort
Escapement	53,869	132,319	PopStat Report			53,158	Mature Cohort * (1-ER_UM)
Catch	32,852	80,695	After NatMort - After PreTerm			32,419	Mature Cohort - Escapement
FRAM TS ER	0.37882	0.37882	Catch/After NatMort	1.00000		0.37882	ER_UM:1-(1-ER_M)^δ
FRAM (ER)	**0.4524**	**0.6903**	(Catch all time steps)/(Catch all time steps + Escapement)		**Bias-Adjusted ER**	**0.4598**	(Catch all time steps)/(Catch all time steps + Escapement)
Relative Bias	**-1.61%**		(FRAM_ER – Bias Adjusted_ER)/Bias Adjusted_ER				

Appendix B

Regional groupings for unmarked stocks.

Stock Name	Stock Number	Hatchery or Wild	Mark Status	Regional Group
Nooksack R	1	Wild	U	NPS
Kendall Ck	3	Hatch	U	NPS
Skookum Ck	5	Hatch	U	NPS
Lummi Ponds	7	Hatch	U	NPS
Samish R	11	Wild	U	NPS
Area 7/7A	13	Wild	U	NPS
Skagit R	17	Wild	U	NPS
Skagit R	19	Hatch	U	NPS
Baker R	23	Wild	U	NPS
Stillaguamish R	29	Wild	U	NPS
Tulalip	33	Hatch	U	NPS
Snohomish R	35	Wild	U	NPS
Snohomish R	37	Hatch	U	NPS
Port Gamble	43	Wild	U	HC
Area 12/12B	45	Wild	U	HC
Quilcene R	47	Hatch	U	HC
Area 12A	51	Wild	U	HC
Area 12C/12D	55	Wild	U	HC
George Adams	57	Hatch	U	HC
Skokomish R	59	Wild	U	HC
Area 13B Misc.	61	Wild	U	SPS
Deschutes R	63	Wild	U	SPS
South Sound NP	65	Hatch	U	SPS
Nisqually R	67	Hatch	U	SPS
Nisqually R	69	Wild	U	SPS
Minter Ck	73	Hatch	U	SPS
Area 13 Misc.	75	Wild	U	SPS
Area 13A Misc.	81	Wild	U	SPS
Puyallup R	83	Hatch	U	MPS
Puyallup R	85	Wild	U	MPS
Area 11 Misc.	89	Wild	U	MPS
Area 10E Misc.	93	Wild	U	MPS
Green R	95	Hatch	U	MPS
Green R	97	Wild	U	MPS
Lake Wash.	99	Hatch	U	MPS
Lake Wash.	101	Wild	U	MPS
Area 10 Misc.	105	Wild	U	MPS

- continued -

Appendix B

Regional groupings for unmarked stocks.

Stock Name	Stock Number	Hatchery or Wild	Mark Status	Regional Group
Dungeness R	107	Wild	U	SJF
Dungeness R	109	Hatch	U	SJF
Elwha R	111	Wild	U	SJF
Elwha R	113	Hatch	U	SJF
East JDF Misc.	115	Wild	U	SJF
West JDF Misc.	117	Wild	U	SJF
Makah Coastal	125	Hatch	U	WAC
Quillayute R Summer	127	Wild	U	WAC
Quillayute R Fall	131	Wild	U	WAC
Quillayute R Fall	133	Hatch	U	WAC
Hoh R	135	Wild	U	WAC
Queets R	139	Wild	U	WAC
Queets R	141	Hatch	U	WAC
Quinault R	145	Wild	U	WAC
Quinault R	147	Hatch	U	WAC
Chehalis R	149	Wild	U	WAC
Chehalis R	151	Hatch	U	WAC
Humptulips R	153	Wild	U	WAC
Humptulips R	155	Hatch	U	WAC
Grays Harbor Misc.	157	Wild	U	WAC
Grays Harbor NP	159	Hatch	U	WAC
Willapa Bay	161	Wild	U	COR
Willapa Bay	163	Hatch	U	COR
Columbia R Early	165	Hatch	U	COR
Youngs Bay	167	Hatch	U	COR
Columbia R OR Early	169	Wild	U	COR
Columbia R WA Early	171	Wild	U	COR
Columbia R WA Late	173	Wild	U	COR
Columbia R Late	175	Hatch	U	COR
Oregon North Coast	179	Wild	U	ORC
Oregon No. Mid Coast	183	Wild	U	ORC
Oregon So. Mid Coast	187	Wild	U	ORC
Oregon South Coast	193	Hatch	U	ORC
Oregon South Coast	195	Wild	U	ORC
California North Coast	197	Hatch	U	ORC
California North Coast	199	Wild	U	ORC
California Central Coast	201	Hatch	U	ORC
California Central Coast	203	Wild	U	ORC

Appendix C

FRAM and bias-corrected estimates of time-step specific exploitation rates[a] for stocks of concern.

Upper Fraser River Wild (Thompson R.) – 0.100 ER guideline:

Time Step	FRAM	BC	$\hat{B}$	Δ
2009				
1	0.000128	0.000128	-0.02%	0.000000
2	0.020853	0.021165	-1.47%	-0.000312
3	0.030164	0.031266	-3.52%	-0.001102
4	0.037944	0.039097	-2.95%	-0.001153
5	0.005102	0.005104	-0.05%	-0.000003
Final	0.094190	0.096760	-2.66%	-0.002570
2010				
1	0.000136	0.000136	-0.01%	0.000000
2	0.012999	0.013115	-0.89%	-0.000116
3	0.026089	0.026746	-2.46%	-0.000657
4	0.036088	0.036798	-1.93%	-0.000711
5	0.003909	0.003904	0.11%	0.000004
Final	0.079220	0.080700	-1.83%	-0.001480

Lower Columbia River Natural (three stock aggregate) – The ER guideline was 0.200 in 2009 and 0.150 in 2010:

Time Step	FRAM	BC	$\hat{B}$	Δ
2009				
1	0.001857	0.001865	-0.45%	-0.000008
2	0.024019	0.025483	-5.75%	-0.001464
3	0.040153	0.044074	-8.90%	-0.003921
4	0.050595	0.055297	-8.50%	-0.004702
2010				
1	0.001448	0.001452	-0.33%	-0.000005
2	0.015068	0.015629	-3.59%	-0.000561
3	0.030465	0.032649	-6.69%	-0.002185
4	0.027043	0.027947	-3.24%	-0.000904

Guideline measured by combining FRAM impacts with mainstem Columbia River fishery impacts (most of which occur in time step 5) outside the model.

[a] Cohort size for the time step, after natural mortality, used as the denominator for the exploitation rate calculation.

Oregon Coastal Natural (three stock aggregate) – 0.150 ER guideline:

Time Step	FRAM	BC	$\hat{B}$	Δ
2009				
1	0.001659	0.001666	-0.43%	-0.000007
2	0.016572	0.017375	-4.62%	-0.000804
3	0.020944	0.022175	-5.55%	-0.001231
4	0.033072	0.033999	-2.72%	-0.000926
5	0.021180	0.021109	0.33%	0.000070
Final	0.093427	0.096324	-3.01%	-0.002898
2010				
1	0.001005	0.001007	-0.24%	-0.000002
2	0.008965	0.009187	-2.42%	-0.000222
3	0.015575	0.016230	-4.03%	-0.000654
4	0.006590	0.006621	-0.46%	-0.000031
5	0.010442	0.010433	0.09%	0.000009
Final	0.042577	0.043477	-2.07%	-0.000900

Southern Oregon | Northern California Coast (two stock aggregate) – 0.130 ER guideline:

Time Step	FRAM	BC	$\hat{B}$	Δ
2009				
1	0.001232	0.001236	-0.33%	-0.000004
2	0.006104	0.006230	-2.02%	-0.000126
3	0.004480	0.004540	-1.31%	-0.000060
4	0.005432	0.005434	-0.03%	-0.000001
5	0.005488	0.005473	0.29%	0.000016
Final	0.022737	0.022913	-0.77%	-0.000175
2010				
1	0.000372	0.000372	-0.09%	0.000000
2	0.002417	0.002436	-0.76%	-0.000019
3	0.004091	0.004141	-1.22%	-0.000051
4	0.000372	0.000372	-0.10%	0.000000
5	0.005485	0.005485	0.01%	0.000000
Final	0.012737	0.012807	-0.54%	-0.000070