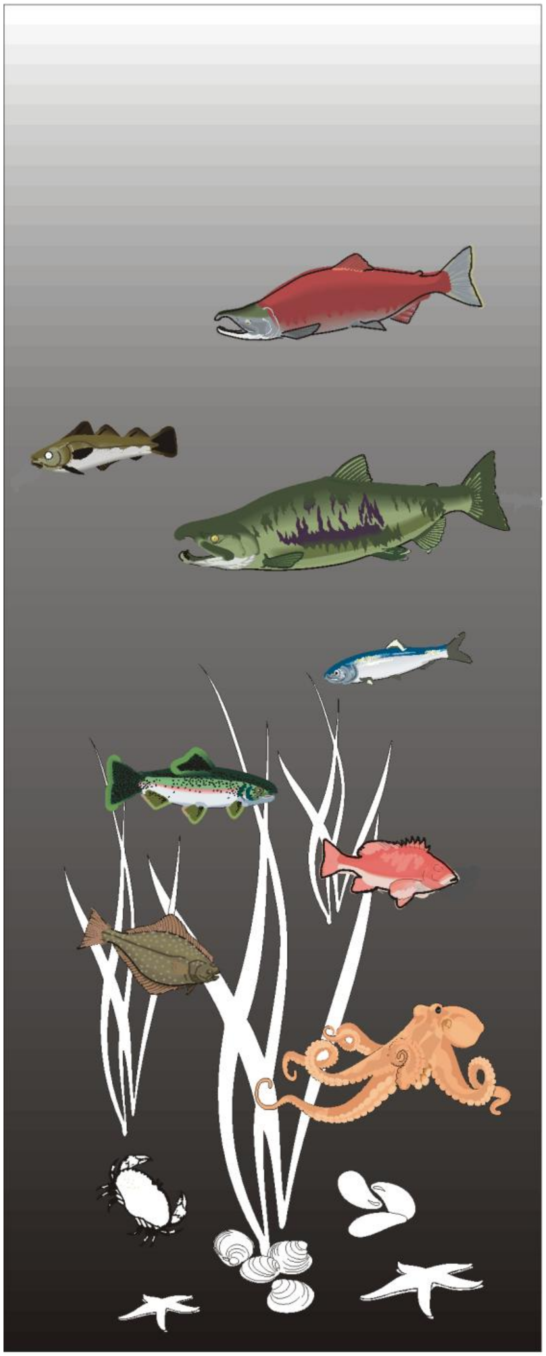
Northwest Fishery Resource Bulletin



Assessment of Two Methods for Estimating Total Chinook Salmon Encounters in Puget Sound/Strait of Juan de Fuca Mark-Selective Chinook Fisheries

by

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and

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Manuscript Series Report No. 2

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EXECUTIVE SUMMARY

Study Background and Intent

Washington Department of Fish and Wildlife's Puget Sound Sampling Unit currently uses two methods to estimate total Chinook encounters in marine recreational mark-selective fisheries. Though both approaches are designed to estimate the same quantity, they often yield differing results, which poses a challenge to the interpretation of post-season estimates of fishery impacts. The two approaches are:

- Method 1 (M1) – M1 estimates of total Chinook encounters are derived from the combination of dockside observations of landed catch and angler interview responses about salmon releases; thus, the accuracy of Method 1 estimates depends heavily on the ability of anglers to correctly recall and report the number of Chinook they actually encountered and released[1].
- Method 2 (M2) – M2 estimates of Chinook encounters are obtained using a combination of creel estimates of legal-size, marked (LSM) Chinook harvest based on dockside sampling and test-fishery data on the relative abundance of LSM Chinook in the targeted (i.e., vulnerable to angling gear) Chinook population. The M2 estimator was derived assuming that anglers retain *all* LSM Chinook encountered, therefore, its accuracy depends on the extent to which angler behavior deviates from this idealized case.

Over several mark-selective Chinook fisheries prosecuted in the marine waters of the Puget Sound/Strait of Juan de Fuca between 2003 and 2007, M1 and M2 estimates of total Chinook encounters have deviated substantially, with the former typically being larger than the latter. Observed differences in M1 and M2 estimates are a product of differing biases in estimates (i.e., relative to the true but unknown number of Chinook encountered in a given fishery) and random sampling variation. With respect to the first factor, past studies and the literature indicate that the assumptions affecting the accuracy of both M1 and M2 estimates are routinely violated to varying degrees. For Method 1, for instance, recall and/or reporting errors are a common feature of angler responses to interview questions requiring precise, quantity-based responses. Of relevance to the accuracy of Method 2 estimates, earlier work demonstrates that anglers occasionally (and purposefully) release LSM Chinook during fishing trips.

The fact that Methods 1 and 2 yield comparable estimates of Chinook encounters in only a subset of cases poses challenges to post-season fishery evaluations and limits the utility of such results to other applications. For example, the existence of diverging estimates of encounters and mortalities renders post-season comparisons of "observed" to projected fishery impacts on unmarked Chinook somewhat subjective. Further, reliable estimates of stock-specific total mortality are needed for catch accounting, cohort run reconstruction, and abundance forecasting. With two divergent estimates, it is difficult to determine which supplies the best estimate to use for these applications. Motivated by these issues, our

[1] Estimates of Chinook salmon harvest are the same for both M1 and M2.

primary goal was to determine if an adjustment to either Method 1 or Method 2 total encounter estimates can be produced that provides an acceptable single estimate of total Chinook encounters, and subsequent total release mortality, for selective fisheries conducted in the marine areas of Puget Sound. To do this, we *i*) characterized seasonal differences in selective fisheries with respect to parameters that may influence the potential for bias in estimates; *ii*) described patterns in the differences between M1 and M2 estimates and quantified their association with fishery characteristics; *iii*) identified and attempted to quantify the potential sources of bias in M1 and M2 estimates; and *iv*) evaluated bias "correction" possibilities for the two estimate types. Based on this combination of objectives and their associated analyses, we identified a potentially suitable bias correction that could be applied to Method 2 estimates of Chinook encounters to obtain a single "best" estimate of total Chinook encounters.

Supporting Analyses and Results

Seasonal Selective Fishery Patterns

We compared Method 1 and Method 2 estimates of total Chinook encounters for 44 discrete time/area/year strata in which Chinook selective fisheries were conducted in the marine waters of Puget Sound and the Strait of June de Fuca between 2003 and 2007. The estimates included both summer (May through September; catch areas 5, 6, 9, 10, and 11) and winter (October through April; catch areas 8-1 and 8-2) fisheries.

Differences (M1-M2) between M1 and M2 estimates of total Chinook encounters ranged from -107 to 7,963 encounters for summer selective fisheries (mean = 3,073) and ranged from -1,903 to 4,049 encounters for winter selective fisheries (mean = 336). The M1 estimate was greater than the M2 estimate 73% of the time across the set of fisheries analyzed. The difference between the estimates exceeded 1,000 fish in nearly half of the cases (45%).

From this evaluation of general M1 and M2 patterns, we concluded that differences in estimates are quite often large enough to limit their utility to management processes. A single, best estimate of total encounters is therefore needed.

Comparison of Seasonal Patterns in Differences and Associations with Fishery Metrics

We compared metrics describing fishery conditions (angling effort and per-capita encounter rates) between summer and winter selective seasons and examined associations between these metrics and differences in M1 and M2 estimates. Results from these analyses demonstrate that there are:

1. *Seasonal differences in fishery characteristics*, with summer selective fisheries exhibiting consistently higher angler effort and lower salmon release rates than winter selective fisheries.

2. *Seasonal differences in M1 and M2 differences*. Absolute differences in M1 and M2 estimates (DIFF = M1 – M2) were greater and more variable for summer than winter fisheries; in contrast, relative differences in M1 and M2 estimates (RATIO = M1/M2) were similar for the two season types.
3. *Significant relationships between M1 and M2 differences and fishery conditions*. Differences in estimates were positively correlated with both fishing effort and salmon release rates but were more strongly related to effort for summer fisheries and more strongly related to release rates for winter fisheries. General patterns of association of fishery predictors with M1 and M2 responses (absolute and relative differences in estimates) were similar; however, the effort and encounter-rate predictors accounted for a greater proportion of the variation in DIFF than for RATIO.

Based on these findings, we concluded that effort and salmon encounter rates (average number of salmon released per angler trip) have a moderating influence on the difference between the M1 and M2 estimates.

Review of Bias in Estimates

For Method 1, we reviewed evidence that suggested a combination of digit bias and prestige bias contributes to M1 over-estimating the true number of Chinook encounters. The first form of recall error involves anglers reporting the number of salmon they encounter as a rounded approximation of what they actually release (e.g., reporting that 10 salmon were released when the true number was actually 9 or 11). Indicative of digit bias, we found that anglers preferentially report salmon releases in numbers ending in 5 and 10 when encounter rates are high. In these instances, we also observed large differences in M1 and M2 estimates (i.e., M1 >> M2). With respect to literature-based estimates of bias due to the over-reporting of releases, the only study available for Puget Sound salmon fisheries suggested that this form of bias can lead to a 40% overestimate of salmon releases, on average.

For Method 2, we evaluated evidence indicating that LSM Chinook release occurs on both an intentional *and* unintentional basis. Voluntary trip report (VTR) and dockside-collected data indicate that anglers intentionally release between four and eight percent of the LSM Chinook that they encounter, with this rate being nearly double for winter compared to summer selective fisheries. Using a novel framework, we estimated the magnitude of unintentional LSM Chinook releases (e.g., due to errors in measurement made by anglers) and determined that it occurs at a similar level (i.e., 4-8%). In contrast to the intentional rate, however, it was estimated to be higher in summer than winter selective fisheries. In combination, intentional and unintentional releases likely contribute to a 12-13% underestimate of actual (true but unknown) encounters by M2.

Consideration of Bias-Correction Possibilities

To identify a single, reliable estimate of total Chinook encounters for selective fisheries, we considered possibilities for correcting bias in estimates generated by both approaches. First, we considered two Method-1 bias corrections, one which attempts to eliminate digit bias (the Beaman–Vaske method) from the raw interview data and another which corrects fishery-total M1 estimates for assumed levels of positive bias levels (combined effect of digit and prestige bias expressed in final estimates). Given that estimates were generally insensitive to the Beaman–Vaske bias correction and that recent, relevant field data on reporting bias (i.e., for use in M1 fishery-total bias correction) are unavailable, M1 bias-correction does not appear practicable at the present time. In contrast, M2 bias correction based on recently collected data on LSM Chinook release rates has promise for application. Finally, we conducted a parameter grid search to identify hypothetical combinations of M1 and M2 bias corrections that minimized summed differences in bias-corrected Chinook encounters estimates. Results from this exercise confirmed that the independent field estimates of M1 bias (+40%, on average, from a prior WDFW study) and M2 bias (-12 to -13%, from VTR and dockside studies) were consistent with M1 and M2 divergence patterns in the observed data.

Recommendations

Based on our analyses and practical considerations, we recommend Method 2 with a correction for the release of legal-size marked Chinook as the preferred method for estimating total Chinook encounters in mark-selective Chinook fisheries. In particular, an "unbiased" estimate of total Chinook encounters could be obtained under Method 2 using:

$$\text{Bias-Corrected M2} = \text{Original M2 Estimate} / (0.87)$$

We recommend that this bias correction be applied to all Method 2 estimates produced through intensive mark-selective fishery monitoring. Also, it may be possible to use this bias correction in cases where an estimate of the total number of LSM Chinook harvested is obtained through less intensive survey approaches (e.g., estimates of total Chinook harvest resulting from the WDFW Catch Record Card [CRC] system, coupled with field estimates of LSM Chinook relative abundance). In addition, to maintain and/or increase the reliability of modified selective fishery estimates in the future, we recommend:

1. If the proposed 13% correction is deemed acceptable, past estimates of total Chinook encounters should be updated and included in a historical data appendix in future post-season reports.
2. Means for reducing the variance of the Method 2 estimates without expanding sampling efforts should be explored (e.g., evaluate variance contributions from dockside and test fishing components).
3. Sampling should continue in mark-selective fisheries so that the data needed to estimate LSM Chinook release rates are periodically obtained. This will enable routine calibration of the proposed bias correction, which may be necessary if/when major changes occur in either fishery regulations or fish populations that might affect

the value of this parameter. Also, where and when it is feasible, fishery-total estimates of intentional LSM Chinook releases should be produced and evaluated relative to the proposed M2 bias correction.

4. As additional CRC estimates of total Chinook harvest become available for the selective fisheries reviewed in this report, estimates of total Chinook encounters generated using the intensive Murthy approach should be compared with those derived from the CRC system. In particular, such an analysis should emphasize understanding the utility of the bias-corrected M2 estimator for generating unbiased estimates of total Chinook encounters with CRC harvest data as the starting point.
5. In fisheries characterized by a large catch-and-release component (mark-selective, salmon, or otherwise), we recommend that estimates of total encounters generated from angler interviews be interpreted cautiously. This recommendation is particularly relevant to situations where apparent encounter rates are high.

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ACKNOWLEDGEMENTS

The analyses and recommendations contained in this document are a result of discussions that began during the Winter 2007-2008 state–tribal review of the Areas 5/6 and 8-1/8-2 mark-selective Chinook fisheries. Thus, the ideas and efforts of several WDFW and tribal staff members contributed to its content. At the Washington Department of Fish and Wildlife, we would like to thank Mark Baltzell, Doug Milward, Laurie Peterson, Kris Ryding, and Steve Thiesfeld for sharing their insight on factors influencing the accuracy of catch and effort estimates generated through the Puget Sound Sampling Unit's (PSSU) mark-selective fishery monitoring program. Also, Mark Baltzell and Karen Kloempken (also WDFW-PSSU) contributed substantially in their data sharing and data management efforts. Finally, we would like to thank the PSSU's sampling supervisors (Steve Axtell–North Sound, Larry Bennett–Strait of Juan de Fuca, Dan O'brien–South Sound, and Slim Simpson–Central Sound) and staff for their diligent and meticulous efforts in collecting the data reviewed herein. We would like to especially acknowledge their willingness to add additional questions to their interview procedures to help inform this present study.

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INTRODUCTION

Washington Department of Fish and Wildlife's Puget Sound Sampling Unit currently uses two different methods to estimate total Chinook encounters in marine recreational mark-selective fisheries. Method 1 (M1) relies on creel survey data to estimate the total number of Chinook harvested and the total number of Chinook released and then apportions the total encounters (estimated number harvested plus estimated number released) to size|mark status categories using test fishery data. Method 2 (M2) relies on the creel survey data to estimate the total number of legal-size, marked Chinook harvested and uses this estimate in combination with the test fishery data to estimate both the total number of Chinook encounters and to apportion the encounters to four size|mark status categories. The four size|mark status categories of interest are:

1. Legal Size and Marked Chinook (LSM),
2. Sub-Legal size and Marked Chinook (SLM),
3. Legal Size and Unmarked Chinook (LSU), and
4. Sub-Legal size and Unmarked Chinook (SLU).

The Method 1 estimate is based on the number of Chinook reported as released by anglers interviewed during the dockside creel survey. These release data are then expanded[2] to estimate a total number of Chinook released[3] by all anglers participating in the fishery with the same methods used to estimate the total number of Chinook harvested. *Method 1 assumes that anglers interviewed during dockside creel surveys accurately report the number of Chinook that they have released*. This assumption may not always be true because: (1) during periods when large numbers of sub-legal size Chinook or other salmon are encountered, anglers may not keep an accurate count of the number of Chinook released (i.e., recall error is likely in fisheries with a large catch-and-release component; NRC 2006); (2) there is evidence of a digit bias or number preference (Vaske and Beaman 2006) in reported release numbers (WDFW 2008a, b), and (3) similar to the "prestige" bias that has been documented for the WDFW Catch Record Card (CRC) system (i.e., an angler who harvests a salmon is more likely to return his/her CRC than an angler who does not harvest a salmon; Conrad and Alexandersdottir 1993), an angler may exaggerate the number of Chinook released so that he/she is viewed as a "good" angler.

Method 2 assumes that anglers do not release any legal-size, marked (LSM) Chinook. The total number of Chinook encountered by the fishery is estimated by dividing the estimated harvest of LSM Chinook[4] based on the creel survey by the proportion of LSM individuals among total Chinook encounters seen in the test fishery. However, available data indicate

[2] The method of expansion used for the creel survey data is the Murthy estimate: see Conrad and Alexandersdottir (1993), WDFW (2008a), and WDFW (2008b) for details.

[3] A portion of "unidentified" salmon releases (i.e., angler-reported salmon releases of unknown species) is also included in the total estimate for the released-Chinook category; these fish are assigned to a species category based on the composition of positively identified, reported salmon releases (see WDFW 2008a, b for details).

[4] Estimates of Chinook salmon harvest are the same for both M1 and M2.

that anglers do release some LSM Chinook, though it is difficult to estimate this release rate accurately (WDFW 2008a, b).

Additionally, both methods assume that the encounter proportions for Chinook in the four size|mark status categories are the same for the test fishery and for the sport fishery as a whole. For Method 1, the test fishery data are used to apportion the total encounters estimated from the shore-based creel survey to the four categories of interest. For Method 2, the test fishery data are used to both estimate total Chinook encounters and to apportion them to the four categories of interest. After apportioning encounters to the four categories, category-specific release estimates are estimated as the difference between category-specific total encounter estimates and the harvest estimates. For this document, we focus exclusively on those assumptions that are unique to each estimate (i.e., accurate recall/reporting of releases under M1 and no LSM release under M2).

Overview of Patterns in Method 1 and Method 2 Estimates

The selective fisheries in the marine areas of Puget Sound have been informally considered as being either "summer" selective fisheries or "winter" selective fisheries. Summer selective fisheries are those that are conducted in the June through (and including) September period and winter selective fisheries are those conducted in the October though April time period. Summer selective fisheries can be characterized as: (1) relatively high effort fisheries; (2) fisheries that are generally directed at maturing Chinook that are migrating through an area; and (3) compared to winter fisheries, fisheries with fewer Chinook released and more salmonid species encountered relative to the number of Chinook harvested. In contrast, winter selective fisheries can be characterized as: (1) relatively low-effort fisheries; (2) fisheries that are primarily directed at resident Chinook that are over-wintering in Puget Sound; and (3) compared to summer fisheries, fisheries with more Chinook released relative to the number of Chinook harvested.

As shown in **Figure 1**, the Method 1 and Method 2 estimates of total encounters deviate significantly from the line of equality (i.e., where Method 1 = Method 2). This is especially true for summer selective fisheries. **Figure 2** compares the estimates from the two methods including approximate 95% confidence intervals. It is clear from **Figure 2** that the precision of the two different estimates also varies considerably. With some exceptions, M2 estimates are generally less precise than their M1 analogs and estimates (M1 and M2) for winter fisheries tend to be less precise than those for summer fisheries.

Appendix Tables A1 and **A2** present the Method 1 and Method 2 estimates for the summer and winter selective fisheries, respectively. These tables also include a description of the time period for each estimate, the estimated effort in the fishery (in angler trips), the estimated harvest of legal-size, marked Chinook, and two statistics describing the magnitude of difference in M1 and M2 estimates of Chinook encounters:

1. the difference in estimates (M1 – M2 = DIFF), and
2. Method 1 divided by Method 2 (RATIO).

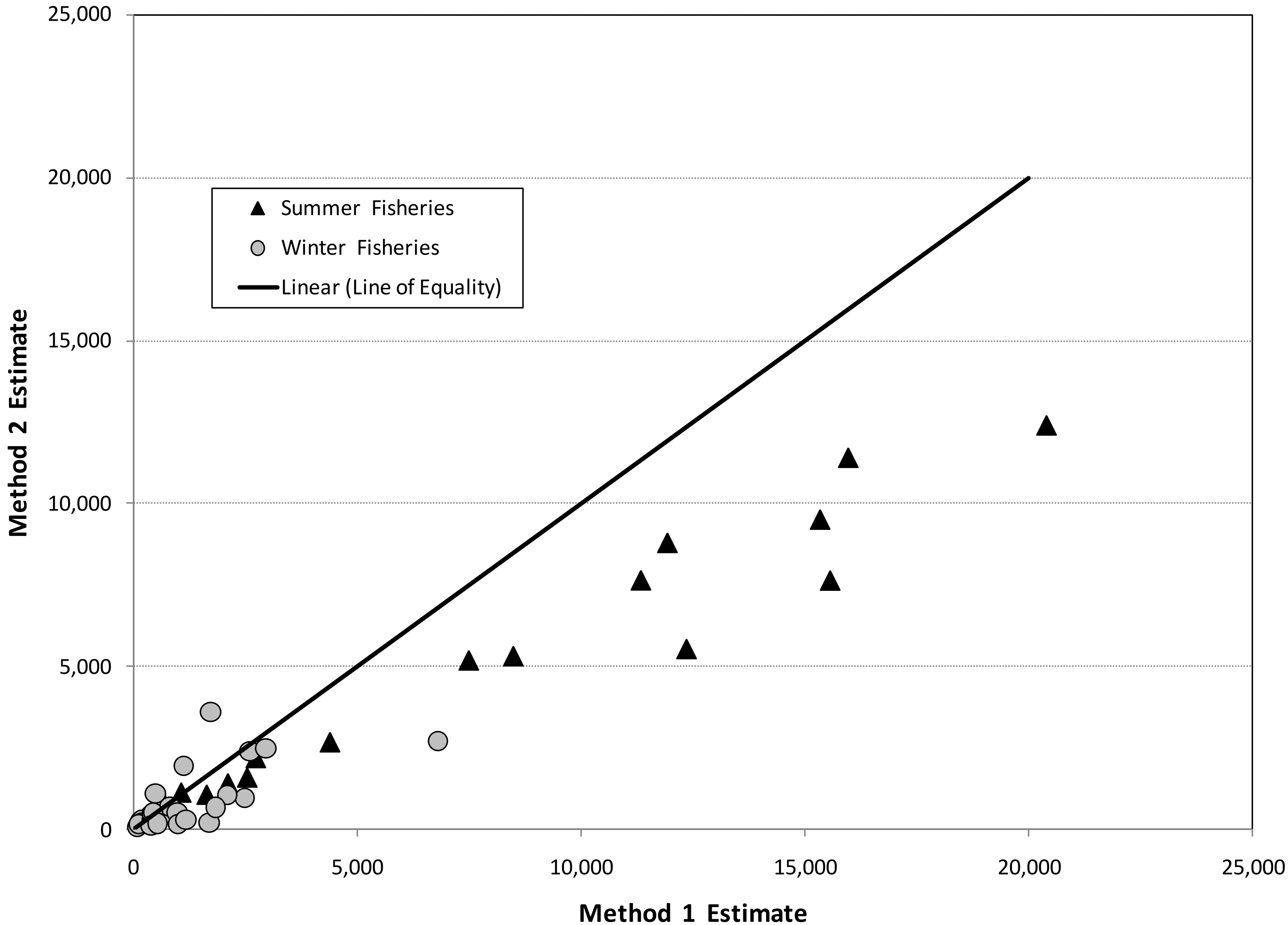

Figure 1. Scatter plot of Method 1 versus Method 2 estimates of total Chinook encounters for Puget Sound selective fisheries, 2003-2007.

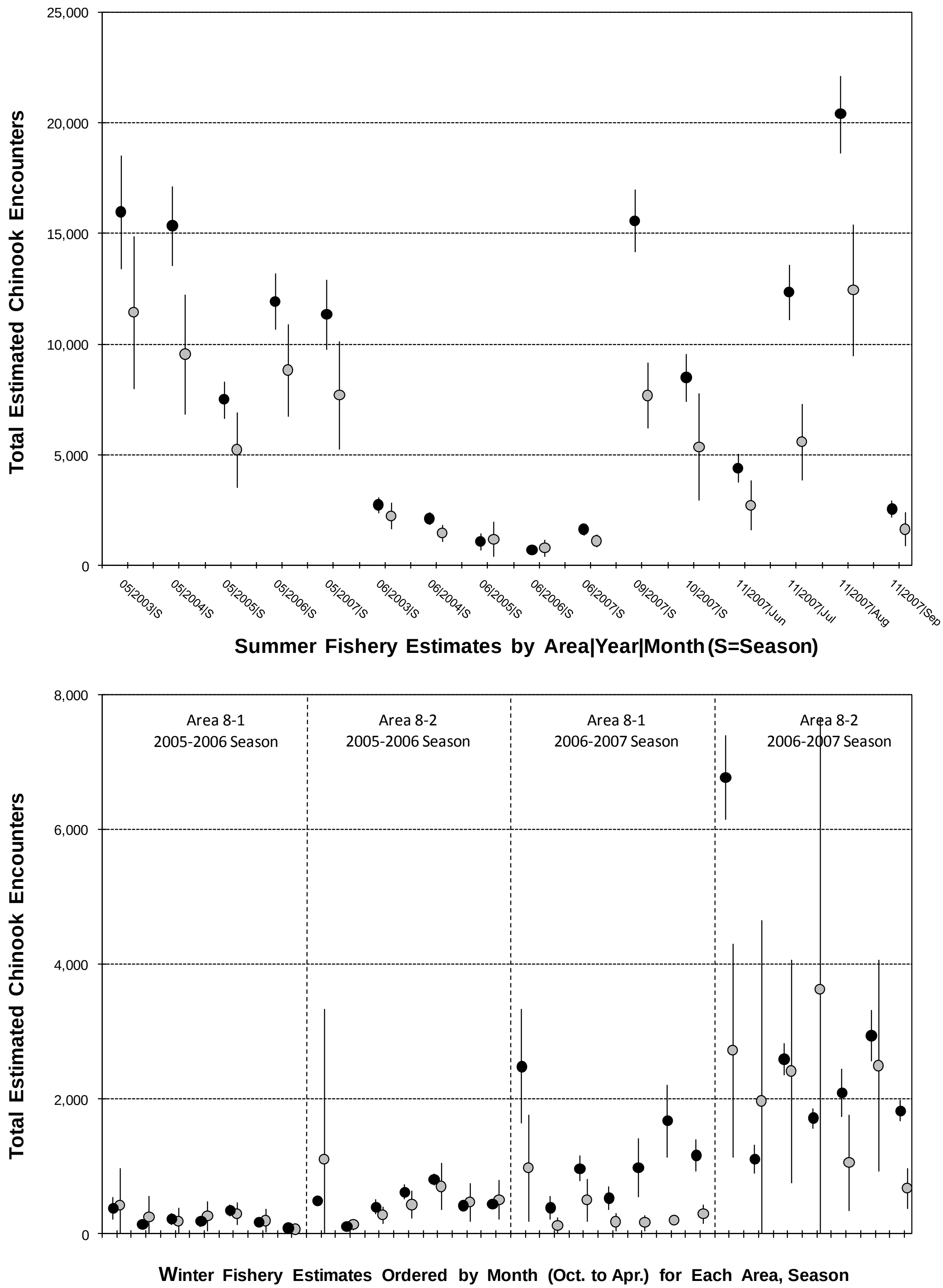

Figure 2. Comparison of Method 1 and Method 2 estimates of total Chinook encounters for Puget Sound selective fisheries, 2003-2007. Method 1 estimates are dark circles and Method 2 estimates are grey circles; approximate 95% confidence intervals are shown.

The average for DIFF is 3,073 Chinook encounters for summer selective fisheries compared to 336 Chinook encounters for winter selective fisheries. The Method 2 estimate is greater than the Method 1 estimate for 36% of the winter selective fishery estimates (10 of 28) compared to only 13% for the summer selective fisheries (2 out of 16). However, in all of these instances, relatively wide Method 2 95% confidence intervals include the corresponding M1 point estimate. On average, Method 1 is 1.9 times greater than Method 2 for winter selective fisheries while the average RATIO for summer selective fisheries is 1.5. Finally, the Method 1 and Method 2 estimates of total Chinook encounters are within 500 fish of each other only 13% of the time (2 out of 16) for summer selective fisheries. In contrast, the two methods are within 500 fish of each other 64% of the time (18 out of 28) for winter selective fisheries.

Report Objectives

The previous section documented the differences between the two methods of estimating total Chinook encounters. About 45% of the time this difference exceeded 1,000 fish, a non-trivial difference for these fisheries. Thus, having two competing estimates of total Chinook encounters for selective fisheries, and therefore two different estimates of the total number of mortalities due to the release of Chinook in these fisheries, is problematic. For example, stock-specific total mortality data are needed for abundance forecasting, cohort run reconstruction, and catch accounting. Further, the existence of diverging estimates of encounters and mortalities renders post-season comparisons of “observed” to projected fishery impacts (i.e., pre-season Fishery Regulation Assessment Model results) somewhat subjective. To help resolve these issues, our objectives were:

1. To characterize seasonal differences in selective fisheries with respect to parameters that may influence the potential for bias in M1 and M2 estimates,
2. To describe patterns in the differences between Method 1 and 2 estimates and quantify their association with fishery characteristics (e.g., effort or per-capita salmon encounter rates),
3. To identify and quantify the potential sources of bias in Method 1 and 2 estimates, and
4. To evaluate bias “correction” possibilities for Method 1 and Method 2.

The over-arching goal of these efforts was to determine if an “adjustment” to either Method 1 or Method 2 total encounter estimates can be produced that provides an acceptable single estimate of total Chinook encounters, and subsequent total release mortality, for selective fisheries conducted in the marine areas of Puget Sound/Strait of Juan de Fuca. Though we consider bias-corrections for both estimate types, an adjustment to Method 2 was deemed preferable at the outset because it might be used in instances where estimates of the total harvest of legal-size marked Chinook are available for a selective fishery from a source other than a Murthy-type creel survey, for example from the WDFW Catch Record Card system.

METHODS

We began our analyses by defining some metrics to characterize selective fisheries and examining whether there was a relationship between the metrics and the difference between the Method 1 and Method 2 estimates of total Chinook encounters.

Comparison of Summer and Winter Selective Fisheries

We compared some metrics calculated to characterize selective fisheries and examined whether differences between the fisheries may require different approaches for resolving the Method 1 versus Method 2 issue. A number of these metrics were estimated from the boat interview data collected during creel surveys and baseline sampling conducted at access sites to the fisheries[5]. For details on the metrics calculated from the boat interview data see **Appendices B** and **C**.

Box-and-whiskers plots were used to compare the distribution for some metrics used to characterize the effort and salmon release|encounter rates in the fisheries. The box-and-whiskers plots encompass the central quartiles of the data (the central 50% of the data values) in the shaded box with the median value indicated by a heavy black line. The box whiskers include all data values not considered outliers or extreme values. Outliers are marked with open circles and are values between 1.5 and 3 box lengths from the upper or lower edges of the box (Hoaglin et al. 1983). Extreme values are marked by asterisks and are more than three box lengths from the upper or lower edges of the box.

Metrics Related to the Differences Between the Methods

For these analyses, we examined the relationships between DIFF and RATIO and a set of metrics related to the selective fisheries. We typically expect the Method 2 estimate to be negatively biased (to underestimate the total number of Chinook encounters) because it assumes that anglers do not release LSM Chinook when we know they do to some degree. Conversely, we typically expect the Method 1 estimate to be positively biased (to overestimate the total number of Chinook encounters) because there is evidence that anglers, on average, tend to overestimate the number of salmon they have released.

Therefore, in most cases we expect the Method 1 estimate to be greater than the Method 2 estimate. Given there is a difference between the Method 1 and Method 2 estimates of total Chinook encounters, we expect the size of this difference to be related to (1) the effort in the fishery and (2) the number of salmon being released, on average, by anglers. For example, anglers on average may overestimate the number of Chinook they have released by only a very small amount, but when combined with a relatively large amount of angler effort in a fishery, this can result in a large overestimate of the number of Chinook encountered. Also, if anglers are encountering and releasing a large number of salmon in a fishery, it may be more

[5] Angler interview data were collected from anglers during creel surveys conducted for the Murthy estimates of effort and catch. In addition, angler interview data were collected during the Puget Sound Baseline Sampling Program from anglers participating in the selective fisheries.

likely that they do not accurately recall the number of Chinook they have released. If the tendency were for anglers to overestimate the number released in these conditions, then we would expect that the difference between the methods might be larger under these circumstances.

We conducted analyses to determine if the data supported these expectations. We examined the relationships using simple Pearson correlation coefficients and scatter plots of the relevant data. We estimated the correlations for the differences between the methods (for both DIFF and RATIO) and angler effort measured as angler trips per day open and for the average number of salmon reported as released by anglers. Angler trips per day open was used as the measure of effort to account for the differences in the number of days encompassed by the different fisheries. Based on the differences between summer and winter selective fisheries, we conducted these analyses separately for each season.

Regression Models with DIFF and RATIO as Dependent Variables

Ordinary least squares (OLS) linear regression was used to examine the relationship between the dependent and independent variables (see **Appendix C** for variables used in the regression analyses and their definitions). A stepwise variable entry procedure was used. At each step, the independent variable not in the equation that had the smallest F-probability was entered, if that probability was ≤ 0.05. Variables already in the regression equation were removed if their F-probability became > 0.10. The stepwise variable entry procedure ended when no more variables were eligible for inclusion or removal.

Regression models with a *Y*-intercept and models forced through the origin were examined when appropriate. Because the coefficient of determination (R^2) cannot be used to compare regression models calculated with a *Y*-intercept to those forced through the origin, three other model evaluation statistics were calculated using a jackknife regression procedure to compare the performance of the candidate models (see **Appendix C**). Models using both untransformed and transformed dependent and independent variables were evaluated. **Appendix C** includes a description of the independent variables examined.

Independent variables that were a measure of angler effort in a fishery and indicators of the number of salmon being encountered by anglers, on average, had consistently high correlations with DIFF (and RATIO to a lesser degree). Therefore, we calculated some new independent variables that were the products of the independent variables which characterized these two fishery measures to see if they improved regression model performance (**Appendix C**). Only the six combined indices that were calculated were submitted to the stepwise OLS regression procedure.

Evaluating Potential Sources of Bias

Both methods of estimating total Chinook encounters in a mark-selective fishery are based on a set of assumptions that were described in the Introduction. We examine potential sources of bias with each method as related to violations of these assumptions.

Method 1 Bias Potential

Relative to the actual number of Chinook salmon encountered in a fishery, Method 1 estimates are likely to be biased if anglers incorrectly report the number of salmon caught and released during a fishing trip[6] for at least two reasons. First, releases-per-boat data collected during interviews often exhibit response-heaping patterns indicative of number preference or digit bias, a form of recall error that results from respondents answering quantity-related questions using rounded approximations of actual events rather than precise counts (e.g., an angler gives a response of 10 when in actuality they released nine salmon; see Vaske and Beaman 2006 for a review). The exact effect of this phenomenon on bias in Method 1 estimates depends on: 1) whether or not anglers have a tendency to consistently round in one direction over another (i.e., upwards or downwards) when responding to interview questions, and 2) the shape of the underlying (true) release—frequency distribution (i.e., is it monotonically decreasing, unimodal, skewed, etc.).

Secondarily, digit bias/number preference effects on Method 1 estimates of total Chinook encounters could operate in concert with prestige bias if anglers have a tendency to round upwards over downwards when responding to quantity-based interview questions. Available evidence suggests that this may in fact be the case for Puget Sound salmon fisheries. Noviello (1998) compared salmon release rates (salmon releases as a percentage of salmon encounters) from on-the-water observations to those obtained during dockside angler interviews for several Puget Sound salmon fisheries conducted during the summer-autumn period in 1997-98. Across several fisheries, Noviello's results (see Appendix E for a summary) indicate that anglers over-report their releases at a rate of 40% (based on a mean on-the-water:dockside-reported release ratio, *R*, of 0.713); however, there was considerable variability among observations (coefficient of variation = 95%). Coupled with its examination of release–frequency data, this study suggested that the discrepancy between on-the-water observations and dockside-reported numbers was due to a combination of prestige and digit bias. Given these observations, we suspect that Method 1 estimates are prone to a positive bias that may be especially pronounced during high salmon-encounter periods.

Third, M1 may contain positive bias due to the assignment of some unidentified salmon to the Chinook category (i.e., see Footnote Number 3). This would only constitute a separate and additional source of bias, however, if assigned-unidentified salmon were in actuality a salmon species other than Chinook. Given that test fishery data suggest otherwise (60-100% of encounters are Chinook) and that the assumed-to-be Chinook portion of unidentified salmon encounters is small relative to observed M1 – M2 differences (5-8% of DIFF on average), we suspect that this issue is of minor concern. For this reason, we do not consider this potential source of bias further in our review.

For the first two sources of bias, we used frequency histograms to examine the number of salmon reported as released by anglers during mark-selective fisheries for evidence of digit bias. We also related release–frequency profiles to the differences between the Method 1 and

[6] As the harvested salmon component is estimated identically for Methods 1 and 2, the potential for bias in estimates due to anglers misreporting harvest (e.g., intentionally concealing it) is not addressed in this report.

Method 2 estimates of total Chinook encounters for a subset of high- and low-encounter cases.

Method 2 Bias Potential

Method 2 can yield biased estimates of total Chinook encounters for at least two reasons. First, Method 2 inaccuracies can result from a systematic difference in the size/mark-status composition of Chinook seen in the test fishery compared to that encountered by the private recreational fleet; positive or negative biases are possible if test fishers encounter LSM Chinook at a lower or higher rate, respectively, than the private fleet. Second, Method 2 will yield estimates with negative bias if anglers release any of the LSM Chinook that they encounter while fishing. While available evidence demonstrates that test fishery assumptions for Method 2 are generally acceptable (WDFW 2008a and 2008b; WDFW unpublished data), the release of LSM Chinook is a concern. To evaluate this source of bias and to inform bias-adjustment possibilities for Method 2 estimates, we examined available information to estimate the magnitude of LSM Chinook release rates.

In a mark-selective fishery, LSM Chinook that are caught may be released for both intentional and unintentional reasons. Most intentional releases are probably because an encountered fish was near the lower limit for LSM Chinook (22 inches). For instance, if an encountered Chinook is of legal size but small in an angler's perception, he/she may choose to release it in order to pursue larger fish. This may be especially true under fairly restrictive bag limits (e.g., two salmon total). We quantified intentional LSM release rates based on angler-reported accounts of encountering and deciding to release LSM Chinook (from voluntary trip reports[7] or dockside interview questions [initiated in winter 2008]).

Additionally, it is possible that anglers unknowingly or unintentionally release a non-trivial number of LSM Chinook due to errors made during the measurement and/or identification process. While test fishers are permitted to bring all encountered Chinook aboard their boats and measure them precisely on metered boards, private anglers are regulated by a handling rule that requires them to measure fish outside of their boats. Thus, some of the fish that would have been classified as LSM in the test fishery may be perceived as being SLM by anglers and therefore immediately released; the reverse may also be true (i.e., an SLM could be incorrectly perceived as LSM). Given the relative abundance of marked 20-24 inch Chinook (i.e., small fish near the legal limit) observed in the test fisheries (i.e., 17.5% on average [range: 0.0-43.4%]; **Appendix D**), unintentional LSM release might also occur.

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[7] Voluntary trip reports, or VTRs, are trip logs that certified anglers (i.e., those that complete a short training session that includes species identification and measurement procedure details) voluntarily complete and return to WDFW to provide information on their fishing efforts and results (i.e., fish caught and either released or harvested, including species, mark-status, and size details).

Estimating unintentional LSM Chinook release rates:

While VTRs and dockside interview data can provide evidence of the extent of intentional LSM release behavior, these data sources do not account for *unintentional* LSM Chinook release. By viewing the steps leading from marked Chinook encounter to harvest or release as a sequence of decisions made by anglers with a given probability (i.e., following a binary decision-tree scheme), coupled with a set of simplifying assumptions, we devised an approach for estimating the unintentional LSM Chinook release rate from a combination of test-fishery and creel data.

To construct a decision-tree model that enables the estimation of the unintentional LSM Chinook release rate, we assumed that:

1. The majority of SLM Chinook retention and unintentional LSM Chinook release is due to errors in measurement made for fish *at or very near* the legal-size threshold; stated differently, anglers generally adhere to the fishery regulations but make mistakes in discrete size (legal or sublegal) classification[8].
2. The probabilities for misidentifying species and/or mark-status class are equivalent for legal and sublegal Chinook salmon (this assumption is required to eliminate a species/mark-status misidentification probability term from the estimation process and is likely true immediately above/below 22 in [56 cm]).
3. The probability of an angler making an error in length measurement (or legal/sublegal discrimination) is roughly equivalent for LSM and SLM Chinook near the size limit.
4. The probability that an angler intentionally releases a fish perceived as being legal does not depend on its true size-class membership (i.e., $p_{\mathrm{rel|SLM}} = p_{\mathrm{rel|LSM}}$).
5. There are no errors in measurement made by test-fishery samplers.

Based on these assumptions, we modeled the Chinook encounter (LSM and SLM only) process according to the following steps (**Figure 3**): 1) upon encounter, an angler identifies a marked Chinook salmon as being either legal or sublegal in size according to probability p_{ID}; 2) if perceived (*correctly or incorrectly*) as LSM, the angler decides whether or not to keep it with probability p_k ($p_k = 1 - p_{rel}$). Given this representation and the usual test-fishery assumptions, LSM and SLM harvest totals are related to total Chinook encounters according to (symbols defined below):

(1) $K_{LSM} = E_{total}\, p_{LSM}\, p_{ID}\, p_K$, and

(2) $K_{SLM} = E_{total}\, p_{SLM}\, (1 - p_{ID})\, p_K$.

By algebraic re-arrangement and substitution, the probability that anglers correctly identify the size class of encountered marked Chinook (p_{ID}) is equivalent to:

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8 In other fisheries governed by size regulations, the non-compliance aspect of this assumption has proven true (e.g., walleye in Minnesota, Page et al. 2004). Further, length-frequency data for SLM Chinook harvested in Puget Sound selective fisheries are distributed in a manner consistent with this measurement error hypothesis (the majority of the sub-legal Chinook that are kept are within an inch [2.54 cm] of the legal-size limit [55% in summer fisheries; 82% in winter fisheries], Appendix **Figure D1**).

(3) $p_{ID} = (K_{LSM}\, p_{SLM}) / (K_{LSM}\, p_{SLM} + K_{SLM}\, p_{LSM})$.

Using this framework, and available sampling results (creel estimates and test-fishery observations), we estimated p_{ID} for all past winter and summer mark-selective fisheries with non-zero SLM Chinook harvest. Thus, working backwards from the K_{LSM} branch in **Figure 3** provides an unbiased Method 2-type estimator for situations where intentional and unintentional LSM release rate (i.e., p_{rel} and 1 - p_{ID}) estimates are available:

(4) $E_{total} = K_{LSM} / (p_{LSM}\, p_{ID}\, [1 - p_{rel}])$.

Symbol definitions:

E_{total} = Total Chinook encounters,

E_{LSM} = Legal-marked Chinook encounters,

E_{SLM} = Sublegal-marked Chinook encounters,

K_{LSM} = Legal-marked Chinook kept by anglers, estimated from dockside observations,

K_{SLM} = Sublegal-marked Chinook kept by anglers, estimated from dockside observations,

p_{LSM} = The probability that an encountered salmon is legal and marked, estimated from test-fishery data,

p_{SLM} = The probability that an encountered salmon is sublegal and marked, estimated from test-fishery data,

p_{ID} = The probability that an angler correctly identifies a fish as belonging to a particular size class (unintentional release probability = 1 - p_{ID}), and

p_{rel} = The probability that an angler releases a marked Chinook that is perceived as being legal in size, $p_K = 1 - p_{rel}$.

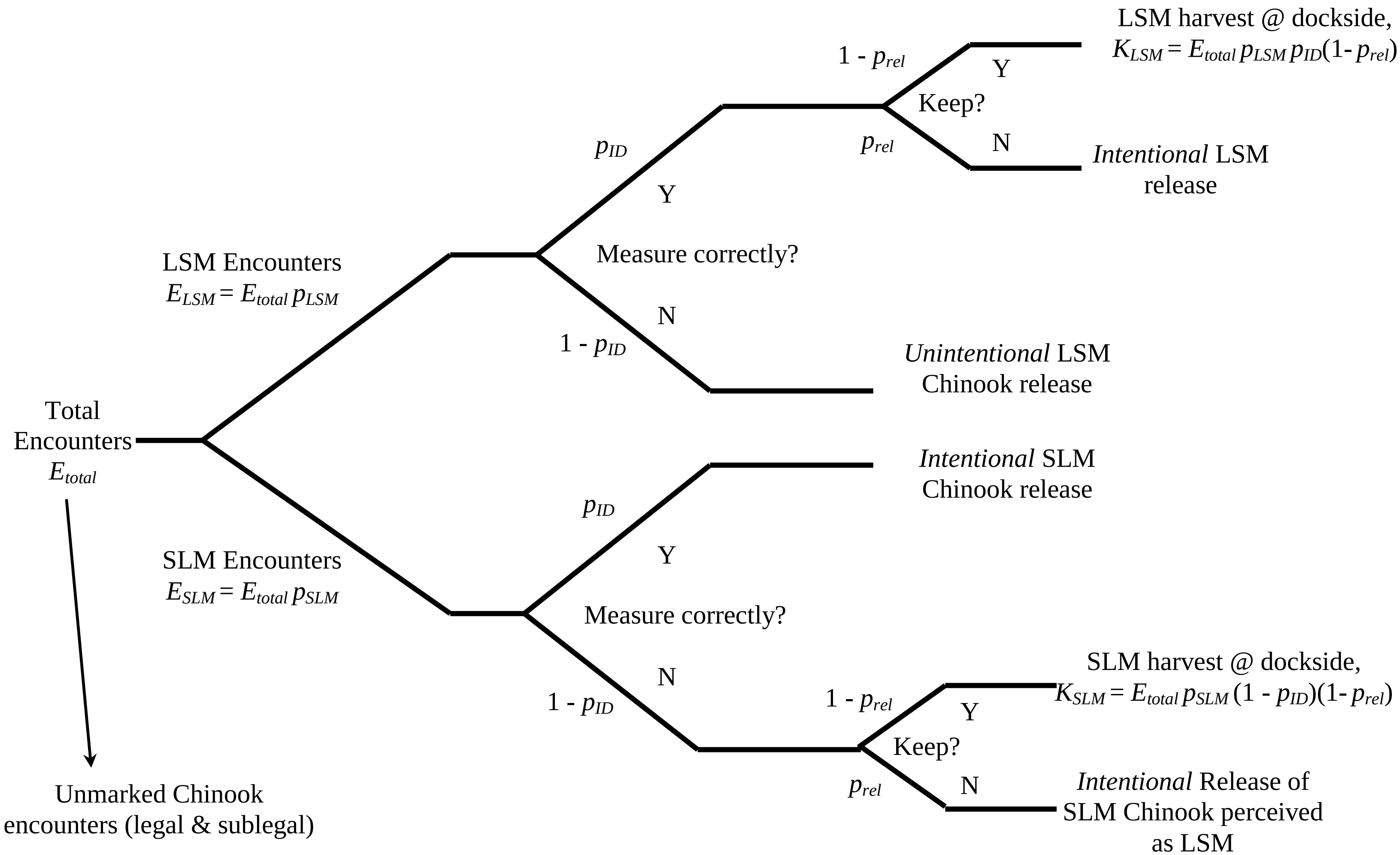


Figure 3. Binary decision-tree diagram characterizing the processes leading from marked Chinook encounter to marked Chinook harvest or release.

Assessment of Methods for "Correcting" Bias in Estimates

In an effort to identify an approach towards obtaining a single, scientifically-defensible estimate of the number of Chinook salmon encountered in a given mark-selective Chinook fishery, we evaluated three methods for "correcting" Method 1 and Method 2 estimates of Chinook encounters. Operating under the assumption that when encounter estimates derived using M1 and M2 differ, it is generally in the direction of M1 exceeding M2, we considered two methods for adjusting M1 estimates downwards and one method for adjusting M2 estimates upwards.

Method 1 Bias Correction

Beaman–Vaske bias-correction method:

First, we evaluated the utility of the Beaman–Vaske (Beaman et al. 1998; Vaske and Beaman 2006) approach for correcting raw interview data where digit or number preference occurs. This bias-correction procedure is built on several assumptions, including:

1. Response heaping occurs.
2. Recall processes result in biases towards specific numbers.
3. Respondents do not intentionally provide erroneous information during interviews.
4. The distribution of heaped responses can be approximated by a smooth response function.

If these assumptions are met, the Beaman–Vaske approach allows for the correction of biases due to response heaping; it does not, however, address prestige bias. For our purposes, the Beaman–Vaske approach involved iteratively fitting quadratic functions to discrete 5 fish-per-boat-trip intervals centered around response heaps, not including the central data point where the heap was observed (e.g., 10 for a 8-12 fish-per-trip neighborhood); and redistributing heaped responses in excess of predicted values to the precise bins within ±2 fish-per-trip of the heap. We repeated this process until the frequency of responses in 5-fish neighborhoods changed little with additional iterations of fitting and redistribution. Upon completion, we compared estimates of sample means and distribution quartiles (i.e., the 25^{th}, 50^{th}, and 75^{th} percentiles) between the raw and bias-corrected dataset. For demonstration/evaluation purposes, we performed this analysis for both a summer and winter period when relatively large numbers of salmon were released by anglers and response heaping was obvious (Area 5, 2003; Area 8-1 2006-7 Season).

Correcting M1 encounters at the fishery-total level:

In addition to our assessment of the Beaman–Vaske approach for bias-correction, we estimated total encounters across an increasing series of release-exaggeration rates:

(5) $$\text{Corrected M1} = \text{harvest} + (R \times \text{releases}_{original})$$

where R is the ratio of true-to-angler-reported salmon releases (i.e., R = 1/[1+exaggeration rate], with the exaggeration rate being calculated relative to actual, but unknown releases). For this exercise, we computed M1 estimates for all area/year/month combinations using possible angler release-exaggeration rates of 20, 30, 40, and 50%. We compared these values with the original M1 and M2 estimates.

Method 2 Bias Correction

Correcting M2 encounters at the fishery-total level:

To assess possible bias-correction options for M2 estimates, we applied a similar approach to that used above for exploring prestige bias corrections for M1 estimates. We computed M2 estimates for all area/year/month combinations using LSM Chinook release rates of 10, 15, 20, and 25% (Note: the LSM release rate [p_{LSMR}] used here is a combined correction accounting for *intentional* and *unintentional* release behavior, i.e., $p_{LSMR} = [1 - p_{\text{rel}i}]*p_{\text{ID}}$) according to:

$$\text{(6)} \qquad \text{Corrected M2} = \text{M2}_{\text{original}} / (1 - p_{LSMR})$$

where $\text{M2}_{\text{original}}$ is equivalent to $K_{\text{LM}}/p_{\text{LM}}$ (**Figure 3**). We contrasted these values with the original M1 and M2 estimates.

Simultaneous Consideration of M1 and M2 Bias Corrections

For the final step of our evaluation of M1 and M2 bias, we conducted a heuristic grid-search exercise to identify a likely set of exaggeration rate and LSM release rate parameters that could have produced the observed dataset. To do this, we produced corrected M1 and M2 estimates under many LSM release rate (combined correction accounting for intentional and unintentional LSM releases, p_{LSMR}) and R (the true-to-reported salmon release ratio, equivalent to $1/[1+p_{exag}]$ where p_{exag} is the proportional exaggeration rate) combinations, within a range guided by the field and literature estimates reviewed in this study.

We assessed all possible p_{LSMR}–R combinations in the ranges of p_{LSMR} between 0 and 0.5 (in steps of 0.01) and R between 0.25 and 10 (in steps of 0.05; the corresponding p_{exag} range was –90% to +300%). For each parameter combination, we: *i*) obtained an adjusted M1 and M2 estimate of total encounters according to Equations 5 and 6, respectively, and *ii*) calculated DIFF based on the adjusted values (M1-M2), for each fishery (area-period combination). We then summed differences across fisheries and inspected the resulting p_{LSMR}–R parameter grid for regions where estimator convergence was achieved (i.e., where ΣDIFF approached zero).

We used our grid search results to address three uncertainties relating to sources of bias in M1 and M2 estimates. First, we identified the magnitude of exaggeration that would have had to occur, on average, if anglers actually kept all LSM Chinook encountered (i.e., $p_{LSMR} = 0$). Second, we evaluated the inverse of the first scenario; that is, we identified the level of LSM release behavior that would have been required to produce DIFF = 0 under a scenario of perfect angler recall (i.e., R = 1 or p_{exag} = 0). Finally, we evaluated whether or not M1 and M2 convergence (ΣDIFF = 0) could be achieved using a p_{LSMR}–R combination that was consistent with available field (p_{LSMR}, see Method 2 Bias Potential above for details) and/or literature (Noviello 1998) information for these parameters.

RESULTS

Comparison of Summer and Winter Selective Fisheries

The number of legal-size, marked Chinook harvested in summer and winter selective fisheries, as well as the angler effort exerted in them, is quite different. Because the summer selective fishery estimates are usually produced for a season while the winter selective fishery estimates are produced for WDFW statistical months, there is a larger range of days encompassed by the estimation periods for summer selective fisheries (13 to 49 days) than for winter selective fisheries (27 to 36 days). Therefore when making comparisons between the seasons, LSM Chinook harvest and angler effort were expressed as harvest and effort per day open, respectively, to account for the differences in the number of days encompassed by the estimates (**Appendix A**). **Figures 4A** and **4B** compare the harvest of LSM Chinook per day open and the effort (in angler trips) per day open for summer and winter selective fisheries. It is evident that much greater Chinook harvest and angler effort occurs in summer selective fisheries compared to winter selective fisheries.

Figures 5A and **5B** compare the average number of salmon released per angler trip for summer and winter selective fisheries. These averages were calculated from the boat interview data collected during the creel surveys and baseline sampling program (**Appendix B**). Typically, more salmon are reported as released per angler trip for winter selective fisheries compared to summer selective fisheries. For summer selective fisheries, the average number of salmon released per angler trip was greater than one salmon per trip for only 25% of the estimation strata (4 out of 16). In comparison, the average number of salmon released per angler trip was greater than one salmon per trip for 50% of the estimation strata (14 out of 28) for winter selective fisheries. All 14 averages greater than 1.0 occurred during the 2006-2007 season in areas 8-1 and 8-2 (**Figure 5B**).

Finally, we compared the DIFF and RATIO estimates for summer and winter selective fisheries (**Figures 6A** and **6B**). While the differences between the methods (DIFF) were generally much greater for summer selective fisheries than winter selective fisheries (**Figure 6A**), the relative differences (RATIO) between the two estimates were much more consistent for summer selective fisheries relative to winter selective fisheries (**Figure 6B**). Only 2 of the 16 RATIO estimates for summer selective fisheries were greater than 2.0 and none were less than 0.8. In comparison, for winter selective fisheries 8 of the 28 RATIO estimates were greater than 2.0 and 6 were less than 0.8.

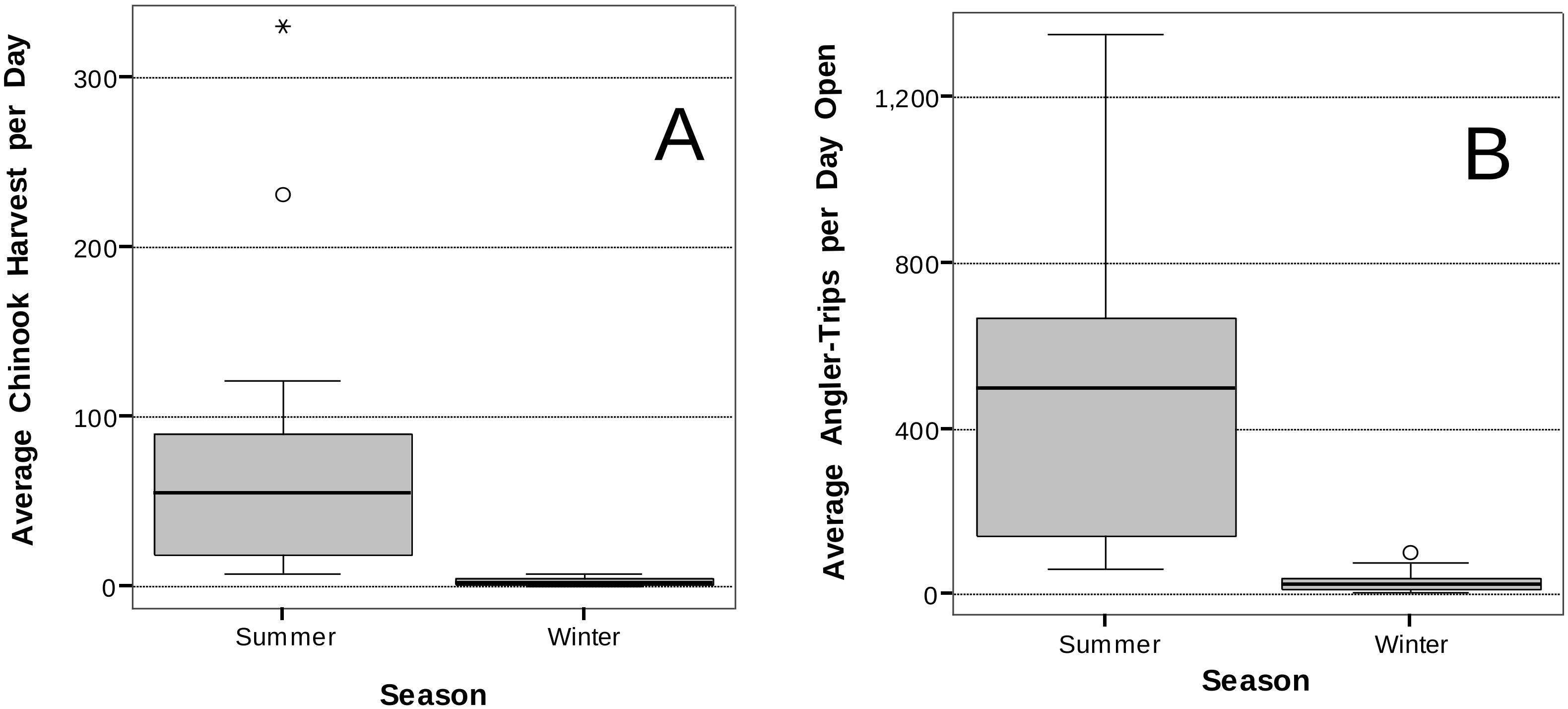


Figure 4. Box-and-whiskers plots comparing (A) the harvest of legal-size, marked Chinook per day the fishery is open and (B) effort in the fishery per day open for summer and winter selective fisheries.

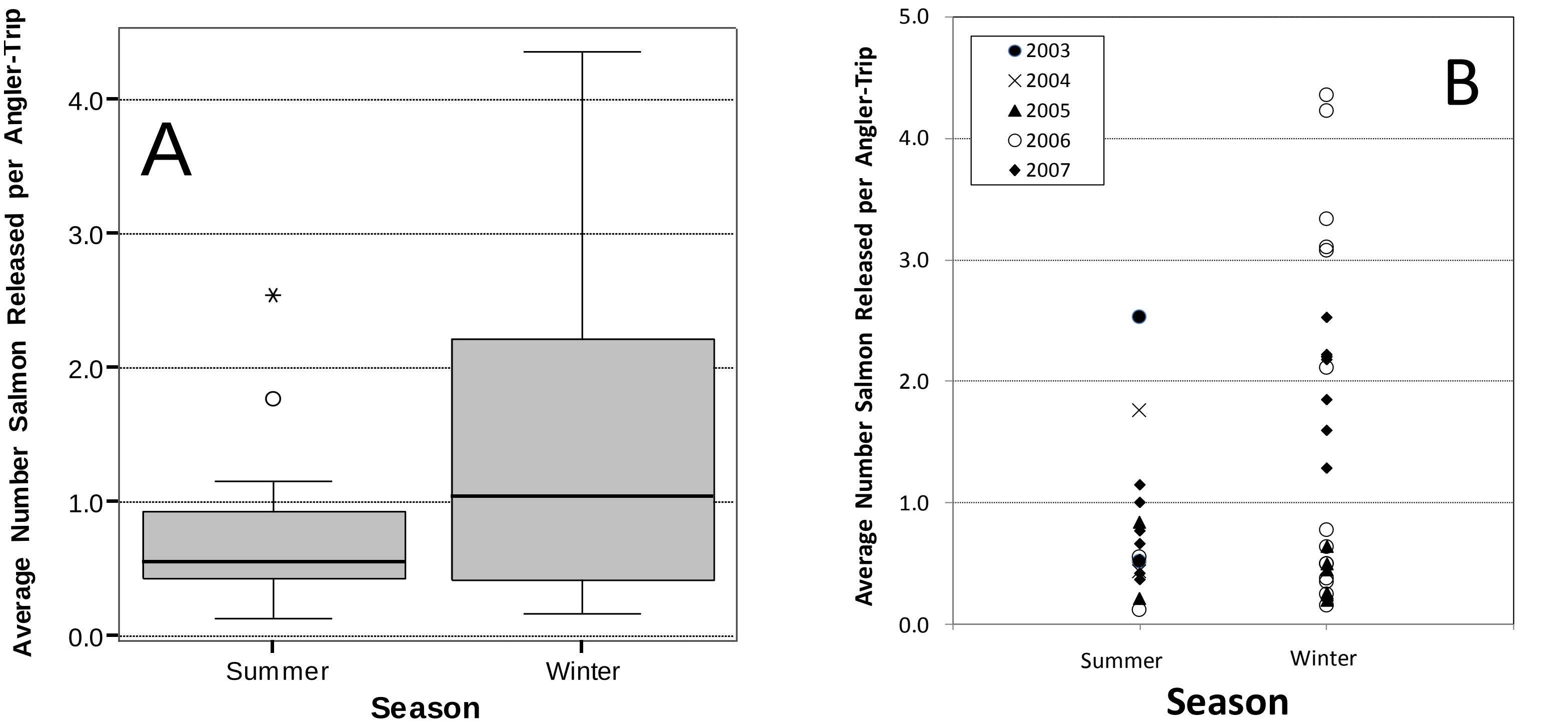


Figure 5. Comparison of the average number of salmon released per angler trip by (A) a box-and-whiskers plot and (B) a dot plot showing the individual means by year for summer and winter selective fisheries. Average releases per angler trip calculated from boat interview data.

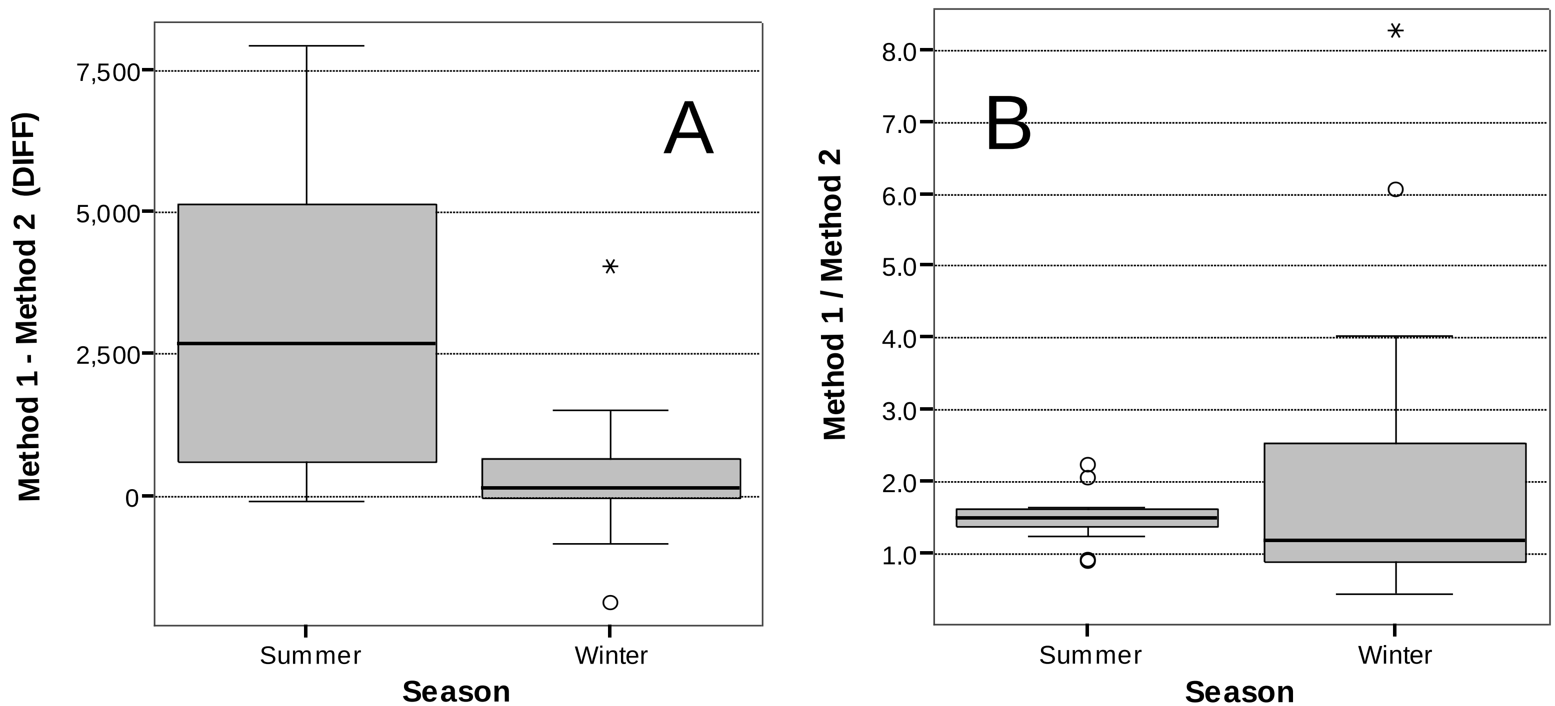


Figure 6. Box-and-whiskers plots comparing (A) the difference between the Method 1 and Method 2 estimates of total Chinook encounters and (B) the ratio of Method 1 / Method 2 estimates of total Chinook encounters for summer and winter selective fisheries.

Metrics Related to the Differences between the Methods

DIFF was highly correlated with angler effort measured as angler trips per day open for summer selective fisheries (r = 0.919, $P \leq 0.001$) but not for winter selective fisheries (r = 0.305, P = 0.114). **Figure 7** illustrates that the difference in total Chinook encounters estimated by the two methods increases as effort increases for summer selective fisheries but not for winter selective fisheries.

DIFF was also correlated with the average number of salmon released per angler trip. The correlation for summer selective fisheries was 0.443 (P = 0.085) and 0.437 (P = 0.020) for winter selective fisheries. Neither was as strongly correlated with DIFF as effort was for the summer selective fisheries (**Figure 8**).

Effort was strongly correlated with RATIO for summer selective fisheries (r = 0.614, P = 0.011) but not for winter selective fisheries (r = -0.139, P = 0.480). Ratio was not strongly correlated with the average number of salmon released per angler trip for either summer or winter fisheries (see **Appendix Figures A1** and **A2**, respectively).

Regression Models with DIFF and RATIO as Dependent Variables

Summer Selective Fisheries

For summer selective fisheries, angler trips per day open was the independent variable most highly correlated with DIFF (see previous section and **Figure 7**). In the stepwise OLS regression procedure this measure of effort was the only variable selected for the model. The next candidate independent variable for selection was total Chinook harvest for the fishery which had an F-to-enter with a significance of 0.063; this was slightly above the F-to-enter criterion. The Y-intercept was not significant (P = 0.561) for the regression model with angler trips per day open as the independent variable (Model 1 in **Table 1**).

Angler trips per day open was the independent variable most highly correlated with RATIO, also. In the stepwise OLS regression procedure this measure of effort was the only variable selected for the model (Model 2 in **Table 1**). There were no other candidate independent variables that were near the significance to enter (next lowest P for F-to-enter was 0.293). The Y-intercept for this model was significant ($P < 0.001$). The adjusted R^2 for this model was only 33%.

The combined index variable which was the product of the legal-size, marked Chinook harvest and the average salmon encounters per angler trip was the combined independent variable most highly correlated with DIFF. The Y-intercept for this model was not significant (P = 0.219). This model (Model 3 in **Table 1**) was not as good a predictor of DIFF as angler trips per day open (Model 1). **Figure 9** compares the results of the jackknife model evaluation procedure for models 1 and 3.

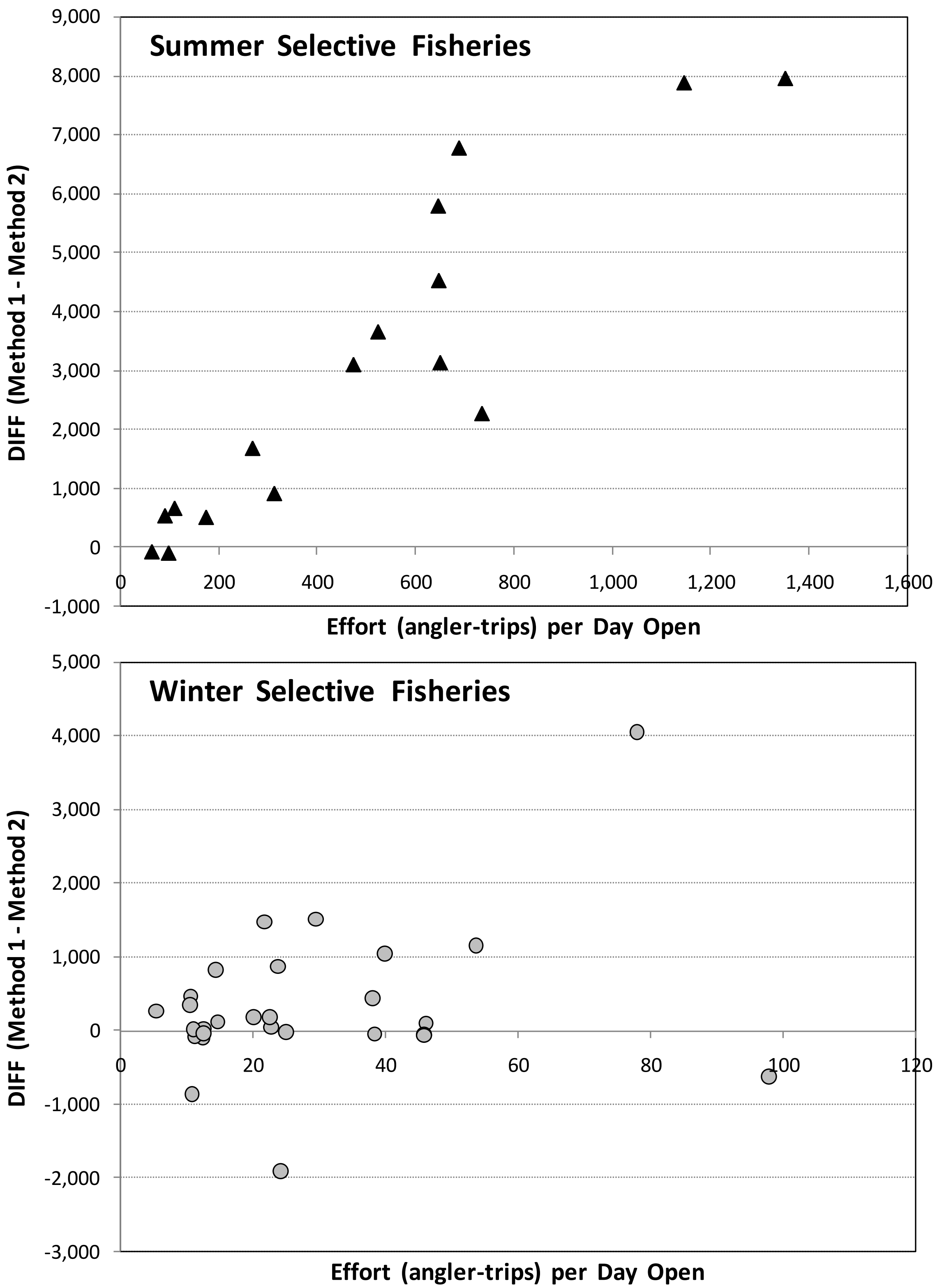


Figure 7. Scatter plot of effort (angler trips per day open) and the difference in total Chinook encounters estimated by Methods 1 and Method 2 (DIFF) for summer and winter selective fisheries.

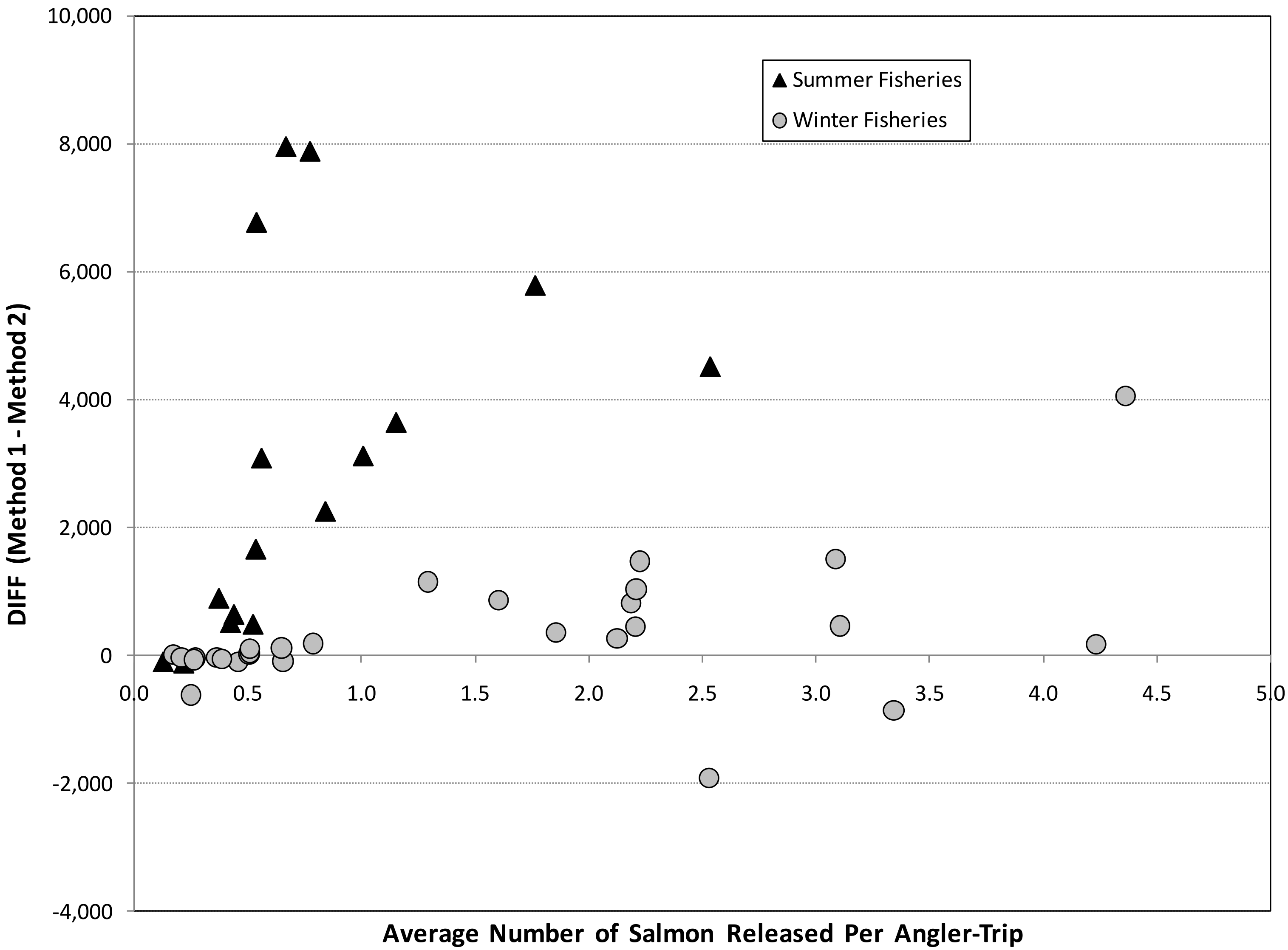
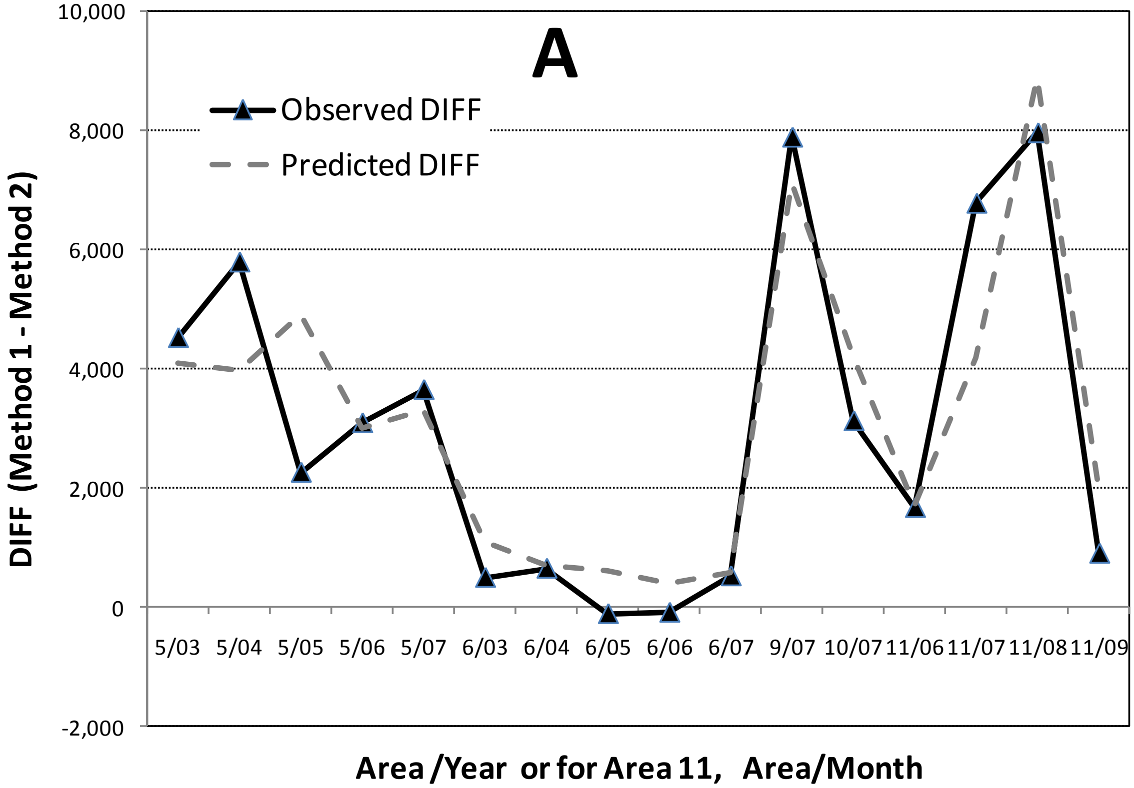


Figure 8. Scatter plot of the average number of salmon released per angler trip and the difference in total Chinook encounters estimated by Methods 1 and Method 2 (DIFF) for summer and winter selective fisheries.

Table 1. Summary of the stepwise regressions used to examine the relationships between the independent variables and DIFF and RATIO.

(Model Number) Season	Dependent Variable	Model Intercept and Independent Variable(s)[a]	Coefficient	Signif-icance	Model Evaluation Statistics[b]			
					Adj. R^2	MPE	MSE	MAPE
(1) Summer	DIFF	Intercept	NA					
		Angler trips / Day Open	6.3734	<0.001	0.925	58%	1,390[c]	111%
(2) Summer	RATIO	Intercept	1.2228	<0.001				
		Angler trips / Day Open	0.000543	0.011	0.333	-4%	0.0930	18%
(3) Summer	DIFF	Intercept	NA					
		Legal-size, Marked Harvest x Average Salmon Encounters PAT	0.9839	<0.001	0.814	36%	3,668[c]	67%
(4) Summer	RATIO	No significant variables						
(5) Winter	DIFF	Intercept	NA					
		Ave. # Salmon Released PAT	271.117	0.004	0.236	51%	1,014[c]	169%
(6) Winter	RATIO	Intercept	-6.266	<0.001				
		% Boats Releasing ≥1 Salmon[d]	0.14315	<0.001				
		% Test Fish Enc. Legal, Marked[d]	0.17541	<0.001				
		Chinook Harvest per Angler trip	-22.695	<0.001	0.701	3%	1.287	73%
(7) Winter	DIFF	Intercept	NA					
		Angler trips per Day Open x Ave. # Salmon Released PAT	10.4268	<0.001	0.587	77%	534[c]	147%
(8) Winter	RATIO	No significant variables						

[a] See **Appendix C** for independent variable definitions.
[b] See **Appendix C** for more details.
[c] x 1,000.
[d] Arc sine transformed.



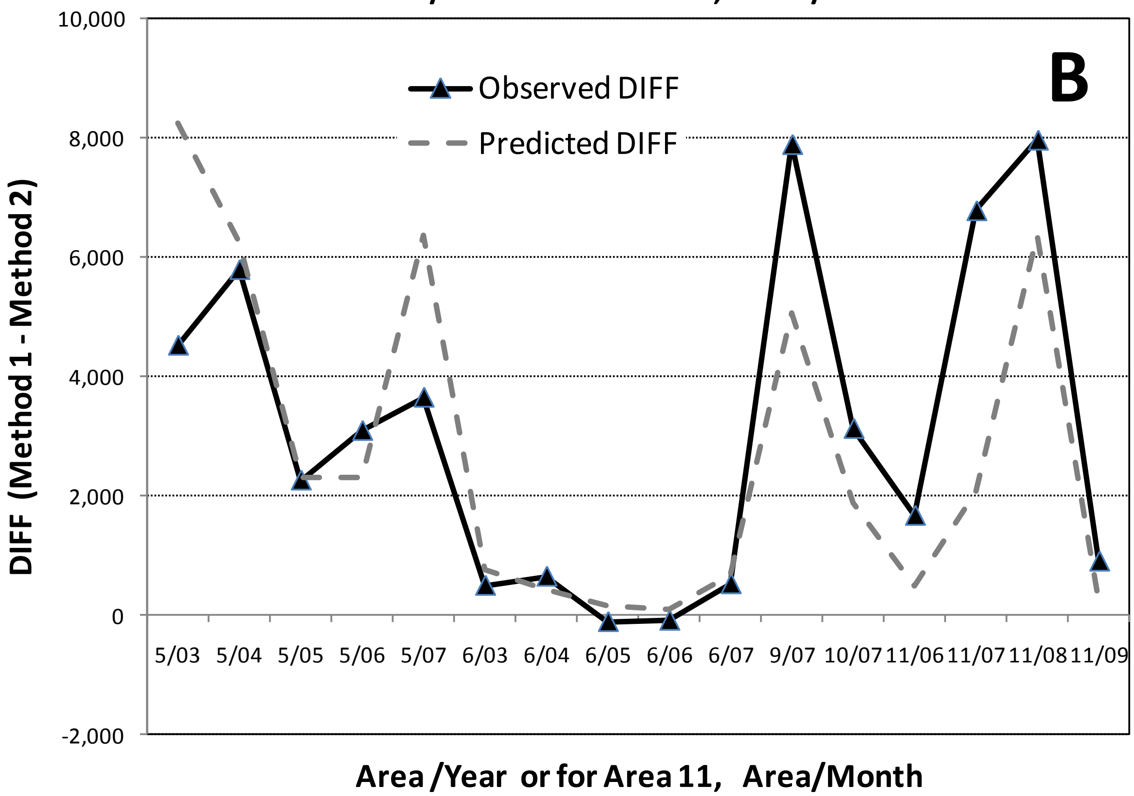


Figure 9. Results of jackknife hind-casting procedure for predicting DIFF with regression models using (A) angler trips per day open (Model 1 in **Table 1**) and (B) a combined index (Model 3 in **Table 1**).

None of the combined index variables were significantly correlated with RATIO (all $P > 0.15$) and none were selected for inclusion in the OLS regression by the stepwise procedure (Model 4).

Winter Selective Fisheries

For winter selective fisheries, the average number of salmon released per angler trip was the independent variable most highly correlated with DIFF (see previous section and **Figure 8**). In the stepwise OLS regression procedure this was the only variable selected for the model. The next candidate independent variable for selection was angler trips per day open with an F-to-enter significance of 0.081. The Y-intercept was not significant ($P = 0.513$) for the regression model with the average number of salmon released per angler trip as the independent variable (Model 5 in **Table 1**).

The percentage of the boats interviewed that released one or more salmon[9] (see **Appendix C**) was the independent variable most highly correlated with RATIO ($r = 0.414$, $P = 0.029$). Two additional variables were entered into the model by the stepwise OLS regression procedure: (2) the percentage[9] of Chinook encountered by the test fishery that were legal-size and marked and (3) the estimated Chinook harvest per angler trip for the fishery (Model 6 in **Table 1**). The Y-intercept for this model was significant ($P < 0.001$).

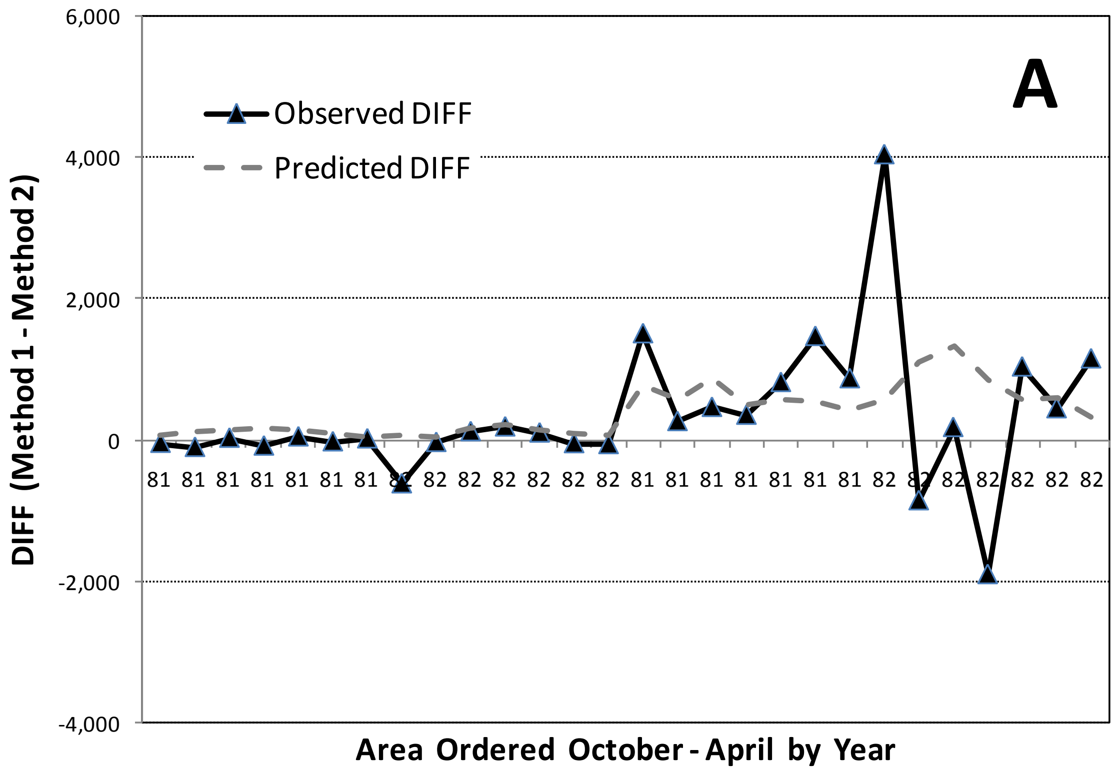
The combined index variable which was the product of angler trips per day open for the fishery and the average number of salmon released per angler trip was the combined independent variable most highly correlated with DIFF. The Y-intercept for this model was not significant ($P = 0.286$). This model (Model 7 in **Table 1**) was a better predictor of DIFF than average number of salmon released per angler trip (Model 5). **Figure 10** compares the results of the jackknife model evaluation procedure for models 5 and 7.

None of the combined index variables were significantly correlated with RATIO (all $P > 0.40$) and none were selected for inclusion in the OLS regression by the stepwise procedure (Model 8).

Method 1 Bias Potential

For Puget Sound/Strait of Juan de Fuca mark-selective Chinook fisheries, available information suggests that recall and/or reporting errors are routinely made by anglers during creel interviews and potentially create a bias in the estimates of total Chinook encounters in the fishery (Noviello 1998). One possible source of this bias is the digit bias discussed previously.

[9] The arcsine of the percentage was used in the regression.



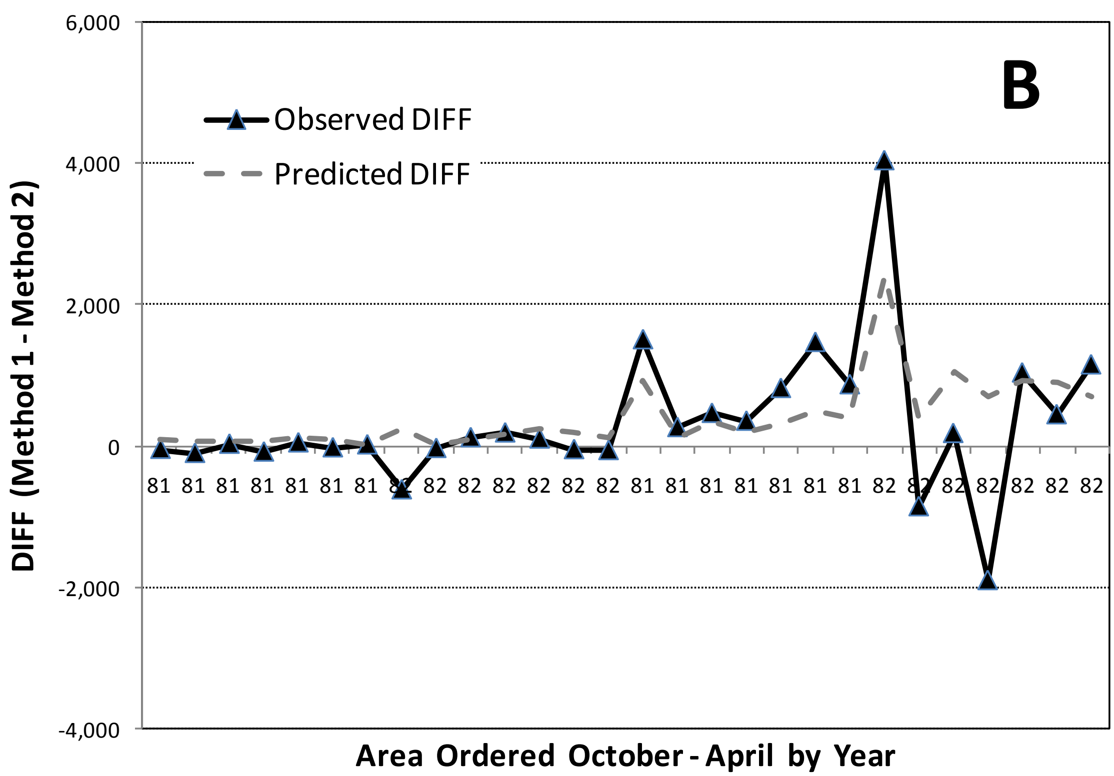


Figure 10. Results of jackknife hind-casting procedure for predicting DIFF with regression models using (A) average number of salmon released per angler trip (Model 5 in **Table 1**) and (B) a combined index (Model 7 in **Table 1**).

Figure 11 compares the frequency for the specified number of salmon reported as being released by boats interviewed in Area 8-1 during the 2005-2006 and 2006-2007 seasons. In 2005-2006, the frequency histogram does not exhibit pronounced digit bias and less than 1% of the boats interviewed released more than seven salmon. In comparison, for the 2006-2007 season the frequency histogram exhibits pronounced digit bias and approximately 20% of the boats interviewed released more than seven salmon. In 2006-2007, the preference for boats to report releasing an even number of salmon is evident for salmon release numbers between 6 and 14.

A preference to report releases in multiples of five is also seen with the relative frequency for releases of 10, 15, and 20 salmon being higher than the numbers near them. Combined over the entire season, DIFF and RATIO for Area 8-1 was:

Season	DIFF (M1-M2)	RATIO (M1/M2)
2005-2006	-144	0.914
2006-2007	5,766	3.383

In 2005-2006 when the number of salmon being released was relatively small, the Method 2 estimate was slightly larger than Method 1. In 2006-2007, however, when relatively large numbers of salmon were being released, the Method 1 estimate of Chinook encounters was about 5,800 fish larger than the Method 2 estimate.

Figure 12 provides a similar comparison for data from two summer selective fisheries. The boat interview data from Area 6 in 2005 do not exhibit pronounced digit bias and less than 1% of the boats interviewed released more than seven salmon. In comparison, for Area 5 during the 2003 season the frequency histogram exhibits pronounced digit bias and approximately 25% of the boats interviewed released more than seven salmon. In Area 5, the preference for boats to report releasing an even number of salmon is evident for salmon release numbers between 6 and 12. A preference to report releases in multiples of five is also seen with the relative frequency for releases of 10, 15, 20, and 30 salmon being higher than expected. DIFF and RATIO for Areas 5 and 6 for the years examined were:

Area	Season	DIFF (M1-M2)	RATIO (M1/M2)
06	2005	-106	0.908
05	2003	4,526	1.396

Similar patterns were seen for the release frequency histograms for all the selective fisheries examined for this report. When the number of salmon reported released per boat was predominately seven or less the differences between the estimates was usually small and the Method 2 estimate was often larger than the Method 1 estimate. When there were more than trivial occurrences for numbers of salmon reported released per boat of eight or more, the Method 1 estimate was always larger than Method 2 and the absolute differences between the estimates were often relatively large.

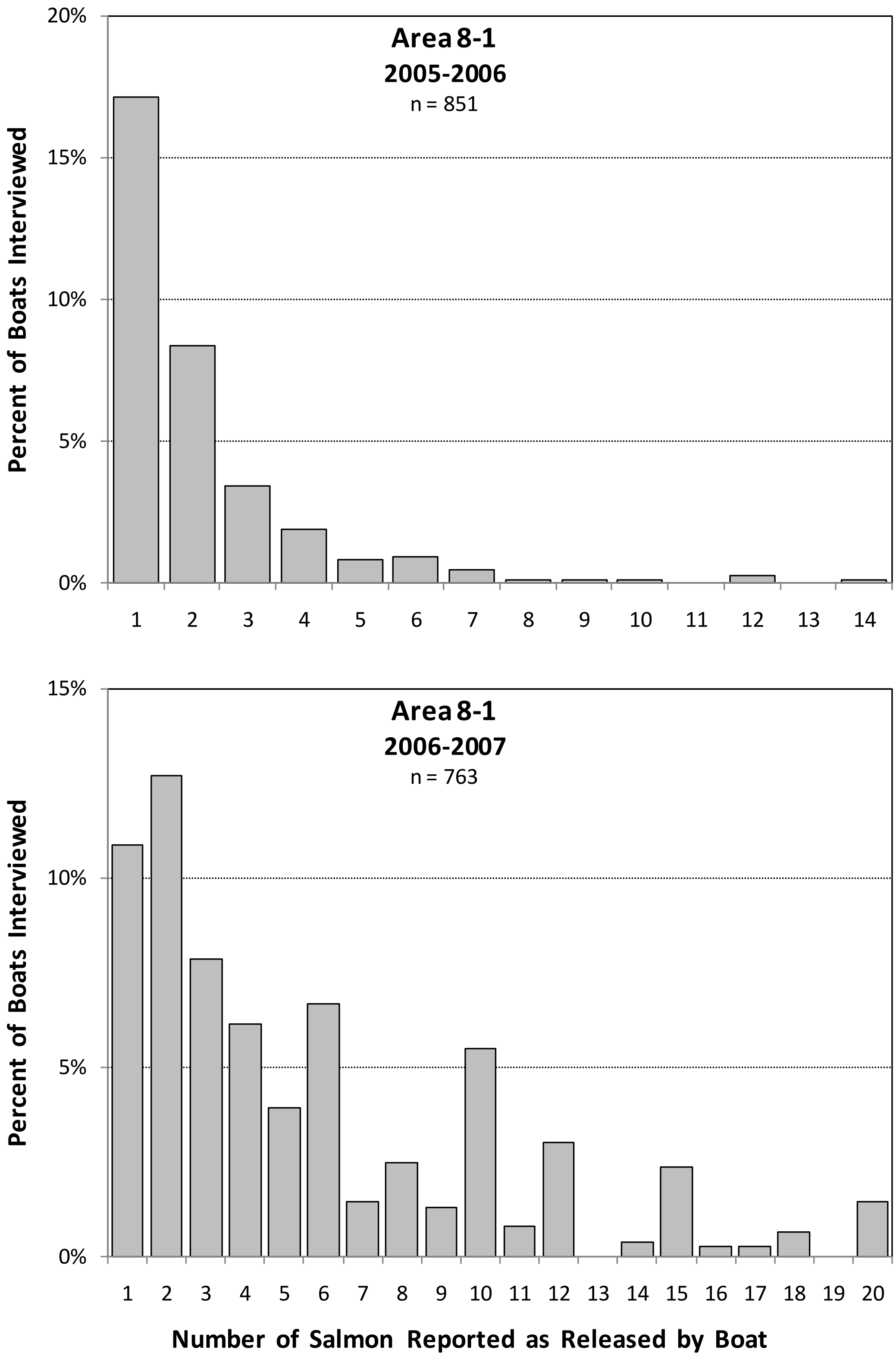


Figure 11. Comparison of the frequency for the number of salmon reported as released by interviewed boats for Area 8-1 in the 2005-2006 and 2006-2007 seasons (n = sample size).

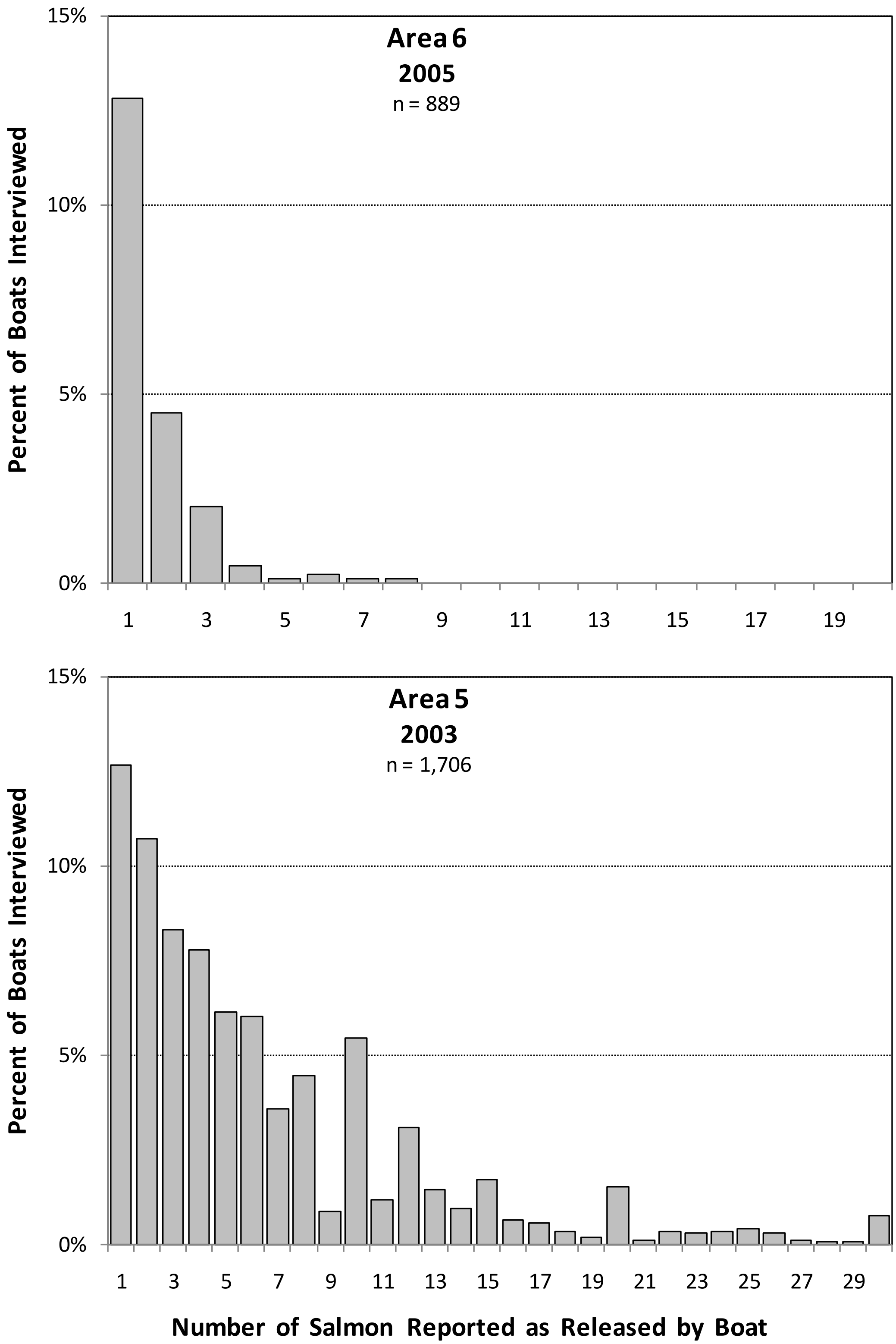


Figure 12. Comparison of the frequency for the number of salmon reported as released by interviewed boats for Area 6 in 2005 and for Area 5 in 2003 (n = sample size).

While we present evidence for digit bias/number preference here, it is likely that for some selective fisheries prestige bias also strongly influenced the patterns observed in the frequency histograms of the number of salmon reported as being released by boats interviewed.

Method 2 Bias Potential

Data available from previous mark-selective fishery studies indicate that both intentional and unintentional LSM Chinook releases occur and likely contribute to negative bias in Method 2 estimates of total Chinook encounters (**Table 2**). VTR and dockside interview data demonstrate that intentional release rates average 4-8% and vary by season (two-sample *t*-test on $\log_e(p_{\text{rel}}+1)$: $t = -2.59$, df = 16.8, $P = 0.019$). In particular, LSM release rates are approximately double for winter (7.6% [range: 5.9-11.1%]) compared to summer selective fisheries (mean = 4.3% [range: 0.0-14.8%]).

Of relevance to the incidence of unintentional LSM Chinook release behavior, we estimated that anglers correctly identified (p_{ID}) the majority of the LSM Chinook that they encountered in past selective fisheries: p_{ID} averaged 0.95 (0.84-1.00; **Figure 13**) across all fisheries and time periods where its estimation was possible and was slightly higher for winter (mean = 0.96) than summer (mean = 0.92) periods (two-sample *t*-test on $\log_e(p_{\text{ID}})$: $t = -1.65$, df = 19.8, $P = 0.115$). Consistent with the expectation that unintentional LSM release rates should be influenced by the relative abundance of just-legal (22-24 in [56-61 cm]) Chinook (i.e., it is assumed to be the result of measurement error at/near the legal size limit), these two variables were significantly and positively correlated ($r = 0.43$, $P = 0.004$; **Figure 14**). Finally, the results from an analysis of the sensitivity of p_{ID} to hypothetical departures from the ideal case (e.g., 0% p_{rel} for SLM Chinook perceived as LSM and differing p_{ID}s for LSM and SLM groups) suggest that our grand-mean estimate of 0.95 is relatively robust.

When combined with the original estimates of total Chinook encounters (i.e., $E_{\text{LM}}/p_{\text{LM}}$), empirical estimates of correct identification probabilities and intentional LSM release rates indicate that Method 2 estimates may be 12-13% negatively biased for both summer and winter fisheries (range: 0-24%; **Table 2**). The pattern of estimated p_{rel} being lower for summer compared to winter selective fisheries and p_{ID} being higher for winter compared to summer selective fisheries resulted in this overall estimate of M2 bias being a good approximation for both seasons (two-sample *t*-test on $\log_e([1-p_{\text{rel}}]*p_{\text{ID}}+1)$: $t = -0.074$, df = 13.3, $P = 0.942$).

Table 2. Estimates of LSM release probabilities for summer and winter mark-selective Chinook fisheries.

Season	Year	Area	Data Source	Total	Kept	Rel'd	p_{rel}	$1\text{-}p_{rel} = p_k$	p_{ID}	$1\text{-}(p_k p_{ID})$ [a]
Summer	2003	5	VTR-private	36	31	5	0.139	0.861	0.879	0.243
	2003	6	VTR-private	28	28	0	0.000	1.000	1.000	0.000
	2004	5	VTR-private	4	4	0	0.000	1.000	0.859	0.141
	2004	6	VTR-private	42	39	3	0.071	0.929	0.940	0.128
	2005	5	VTR-private	9	9	0	0.000	1.000	0.919	0.081
	2005	6	VTR-private	13	13	0	0.000	1.000	1.000	0.000
	2006	5	VTR-private	10	10	0	0.000	1.000	0.843	0.157
	2006	6	VTR-private	7	7	0	0.000	1.000	-- [b]	-- [b]
	2007	5	VTR-private	20	19	1	0.050	0.950	0.837	0.205
	2007	6	VTR-private	16	16	0	0.000	1.000	-- [b]	-- [b]
	2007	9	VTR-private	61	52	9	0.148	0.852	0.885	0.245
	2007	10	VTR-private	7	6	1	0.143	0.857	0.969	0.169
	2007	11	VTR-charter	163	159	4	0.025	0.975	0.964 [c]	0.060
	2007	11	VTR-private	61	57	4	0.066	0.934	0.964 [c]	0.099
	2007	13	VTR-private	11	11	0	0.000	1.000	--	--
						Summer Grand Mean =	**0.043**	**0.957**	**0.922**	**0.127** [e]
Winter	2005-06	8-1	VTR-private	17	16	1	0.059	0.941	0.927 [c]	0.128
		8-2	VTR-charter	83	76	7	0.084	0.916	0.955 [c]	0.126
	2006-07	8-1	VTR-private	9	8	1	0.111	0.889	0.959 [c]	0.148
		8-2	VTR-charter	43	39	4	0.093	0.907	0.988 [c]	0.104
	2008	7	Dockside Interview	417	388	29	0.070	0.930	-- [d]	-- [d]
	2007-08	8-1	Dockside Interview	91	83	8	0.088	0.912	-- [d]	-- [d]
	2007-08	8-2	Dockside Interview	225	208	17	0.076	0.924	-- [d]	-- [d]
	2007-08	9	Dockside Interview	149	138	11	0.074	0.926	-- [d]	-- [d]
						Winter Grand Mean =	**0.082**	**0.918**	**0.957**	**0.126** [e]
									All Seasons Grand Mean =	**0.127**

[a] Equivalent to the probability of an angler releasing a LSM Chinook (either intentionally or unintentionally).
[b] Not estimable due to small test-fishery sample size (i.e., no SLM Chinook were encountered).
[c] Season-wide average of monthly estimates.
[d] Estimates of p_{ID} not available because post-season numbers have not been finalized yet.
[e] Computed as 1 - (product of p_{ID} and p_k means), summer and winter values are 0.882 and 0.881, respectively.

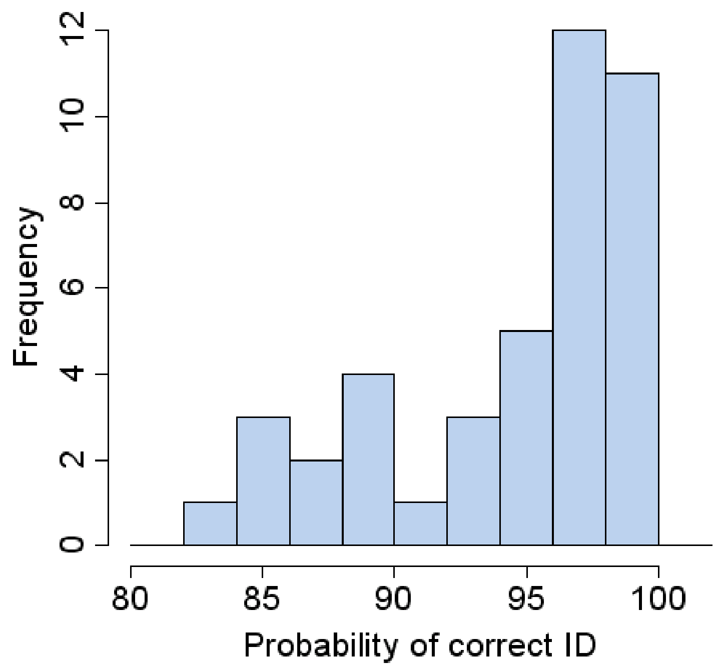


Figure 13. Histogram of correct-identification probability (p_{ID}, as a percentage) estimates for selective fisheries monitored between 2003-2007 (n = 42 area-period combinations total).

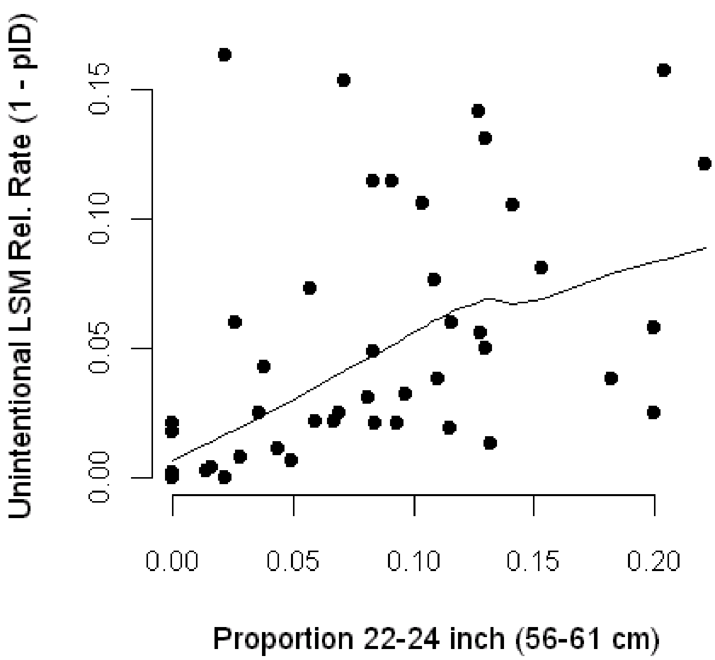


Figure 14. Scatter plot of the unintentional LSM release rate (i.e., 1 - p_{ID}) versus the proportion of just-legal (22-24 inch [56-61 cm]) Chinook salmon present in the test fishery. The solid line is a loess-smoothed trend line.

Assessment of Methods for "Correcting" Bias in Estimates

Method 1 Bias Correction

Beaman–Vaske bias-correction method:

We applied the Beaman–Vaske bias-correction approach to creel data collected in summer and winter fisheries during periods with high salmon encounter rates (i.e., Area 8-1, 2006-7 Season; Area 5, 2003 Season). In both datasets, response heaping was evident for release numbers ending in 5s and 10s when total Chinook releases equaled or exceeded ~10 Chinook per boat trip[10]. Based on these observations, we redistributed heaped responses for three release values (i.e., 10, 15, and 20 releases per trip; **Figure 15**) evident in the Area 8-1 dataset and two that were apparent in the Area 5 dataset (i.e., 10 and 15 releases per trip; **Figure 15**). Though there was evidence for heaping on even-numbered responses below 10 releases-per-trip, we could not correct for these because: *i*) an analytical means for redistributing values across small (i.e., ±1) and overlapping neighborhoods is currently lacking from the Beaman–Vaske approach; and *ii*) it is likely that the accuracy and precision of angler recall is relatively high below this threshold. For both the Areas 8-1 and 5 datasets, four iterations of successive model fitting and data redistribution produced adequate data-smoothing results (i.e., no change in releases-per-trip frequency occurred with an additional iteration).

Though visibly different (**Figure 15**), the release–frequency distributions derived through number-preference/digit-bias correction were nearly identical to those obtained from the original release–frequency data on a summary-statistic level. With the exception of the upper quartile in 8-1 (75th percentile for original compared to corrected distribution in 8-1: 9 and 8 fish per boat trip, respectively), quartiles of the original and bias-corrected distributions were identical for both Marine Areas (Area 5 percentiles: 25th = 1, 50th = 2, and 75th = 5 fish per boat trip; Area 8-1 percentiles: 25th = 2 and 50th = 4). Further, the mean number of salmon released per boat trip derived from the bias-corrected distribution (3.77 and 6.09 releases per boat trip, Area 5 and 8-1 respectively) was within 1% (but less than) of what was estimated from the original dataset (3.78 and 6.12 releases per boat trip, respectively). Though it is possible that the modest differences in means could translate into a larger difference in fishery-total estimates (i.e., due to expansion procedures governed by the sample design), these results suggest that at least for the most obvious cases, response heaping accounts only marginally for the positive bias in M1 estimates.

[10] In addition to 5/10 heaping, a response heap was evident at 12 fish per boat trip in both the Area 8-1 and 5 dataset; to facilitate our application of the Beaman–Vaske bias-correction method to the more persistent and recurring 5/10 heaps, we modified the initial input dataset so that observed responses of 12 fish-per-trip were uniformly allocated to 11, 12, and 13 (J. Beaman, personal communication).

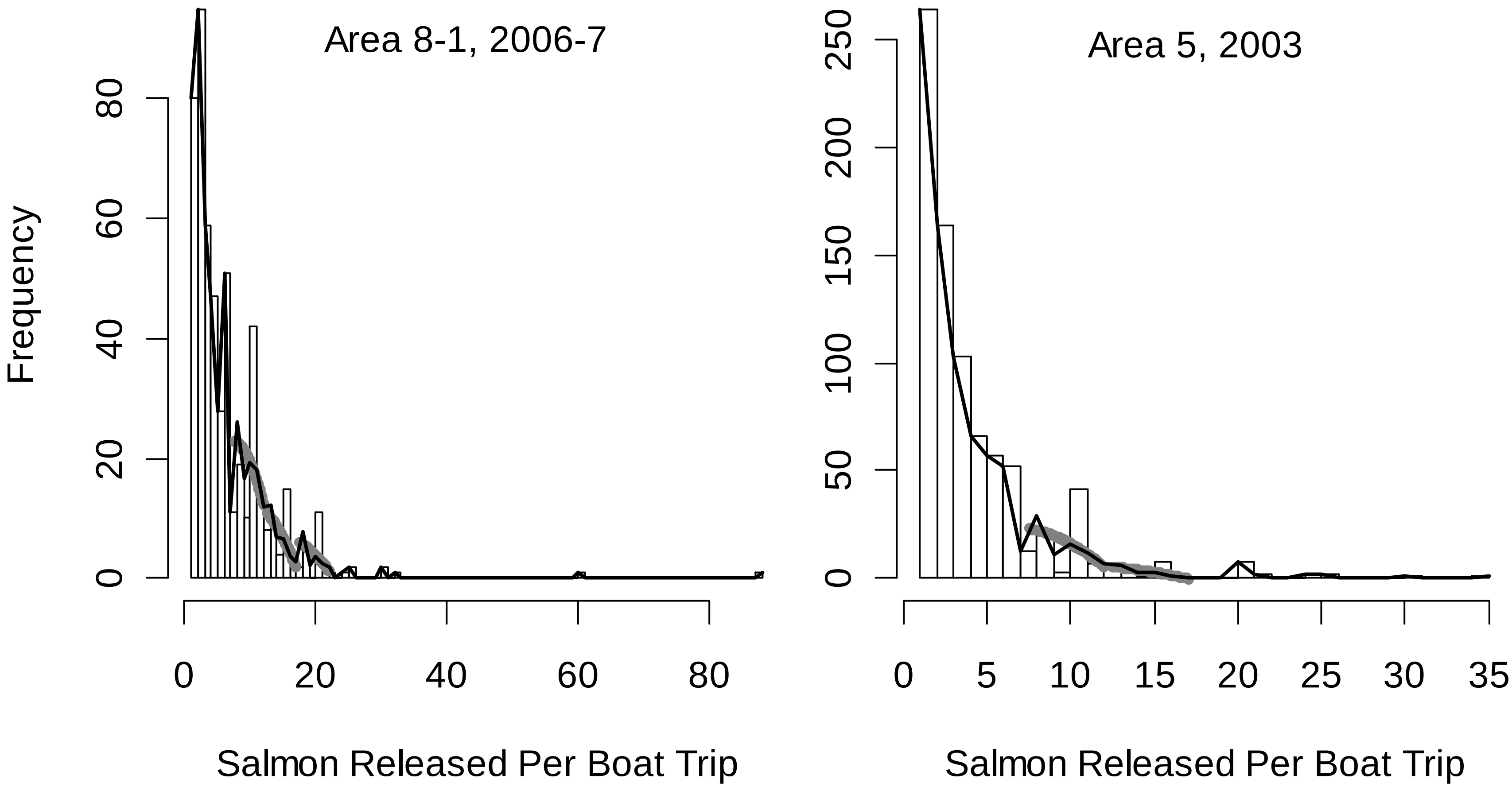


Figure 15. Application of the Beaman–Vaske digit bias correction method to salmon release data for Puget Sound mark-selective Chinook fisheries. Bars reflect the frequency at which anglers reported releasing varying numbers of salmon during their fishing trips; gray curves reflect fitted frequency functions for parties reporting releases on non-heaping values (i.e., quadratic functions fitted to ±2 observations centered around heaped values). Solid black lines reflect the corrected data based on four iterations of smoothing.

Correcting M1 encounters at the fishery-total level:

Beyond correcting elemental data for digit bias/number-preference errors made by anglers during the recall process (i.e., the Beaman–Vaske method), using Equation 5, we applied bias corrections based on a range of plausible exaggeration rates (20-50%) from Noviello (1998) to M1 releases at the fishery-total level (**Appendix Table E1**). For most summer fisheries, corrections based on an assumed 40-50% exaggeration rate (i.e., R range 0.71-0.67) yielded encounters estimates that were approximately half way between the original (unmodified) M1 and M2 estimates (**Appendix Figure E1**). Given their proportionally higher released Chinook component, the effect of these same reductions on winter-fishery M1 encounters was less pronounced. Finally, all levels of M1 reduction yielded estimates of encounters that were less than the original M2 estimates for low encounter-rate areas/years (e.g., Areas 8-1 in 2005-6 and Area 6 in all years).

Method 2 Bias Correction

Correcting M2 encounters at the fishery-total level:

Following the same approach used for M1 bias correction, we applied arbitrary but plausible bias corrections to M2 estimates of Chinook encounters. From this we observed that incorporating relatively small (~15%) LSM release rate adjustments into M2 estimates produced more striking changes in "corrected" M2 values than did equivalent M1 bias corrections (**Appendix Figure E2**). This is an artifact of the estimator's structure.

Simultaneous Consideration of M1 and M2 Bias Corrections

We conducted a grid search exercise in order to identify combinations of LSM release rates (p_{LSMR}) and exaggeration rates (p_{exag} or $1/R$ - 1) that could minimize differences between M1 and M2 encounters estimates. In total, we considered 2,040 p_{LSMR}-R combinations, which produced Σ(M1-M2) values that ranged from 1.2 million (p_{LSMR} = 0; R = 10 or p_{exag} = 0.90) to –145,000 (p_{LSMR} = 0.50; R = 0.25 or p_{exag} = 3.0) and averaged ~25,000. A visualization of grid-search results highlighted the clear, compensatory effects of bias sources for the two different estimators: a virtually infinite but mathematically related set of bias parameter combinations (i.e., p_{LSMR}-R) could have yielded the observed data (**Figure 16** and **Appendix Table E2**).

In terms of the three uncertainties assessed from grid-search results, first we observed that for M1 and M2 to be equal (ΣDIFF = 0) under a zero LSM release scenario (i.e., p_{LSMR} = 0), anglers would have had to exaggerate actual releases by ~80% (R = 0.56). Second, for the same result (i.e., ΣDIFF = 0) to be achieved under a zero-exaggeration scenario (i.e., R = 1 or p_{exag} = 0), anglers would have had to release 35% (combined intentional or unintentional rate) of all LSM Chinook encountered. Finally, this exercise demonstrated that the p_{LSMR}-R combination based on field estimates of these two parameters (p_{LSMR} = 0.127 [grand mean in **Table 2**] and R = 0.71 or p_{exag} = 0.40 [mean of values in **Appendix Table E1**]) led to M1 and M2 convergence.

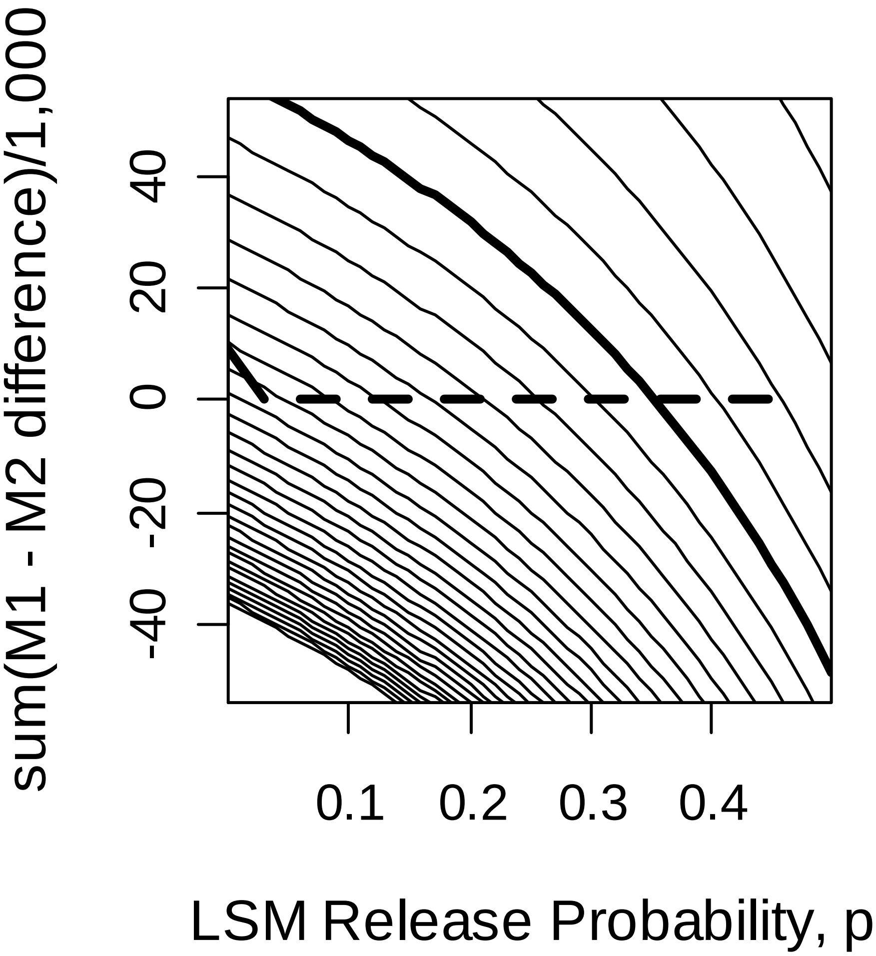


Figure 16. Summed differences (across fisheries) in adjusted M1 and M2 estimates as a function of varying bias corrections for legal-size, marked Chinook releases (inclusive of intentional and unintentional, i.e., p_{LSMR} = [1-p_{rel}]*p_{ID}) and proportional exaggeration rates (the contours [p_{exag} = 1/R –1], which are displayed in 10% increments). The bold central contour represents the line of zero exaggeration (i.e., p_{exag} = 0 or R = 1). The area above the bold curve corresponds to a region of M1 correction due to assumed under-reporting whereas that below the curve reflects corrections made for positive exaggeration. The dashed horizontal line corresponds to the line of equality for adjusted M1 and M2 estimates (DIFF = 0). For reference, the location of a data point based on the original unmodified M1 (p_{exag} = 0) and M2 estimates (p_{LMR} = 0) would appear just outside the extreme upper left-hand corner of the plot ([sum of M1 – M2 differences]/1,000 = 59). See **Appendix Table E2** for a grid-based display of these results.

DISCUSSSION

In this report, we presented data and analyses that support a framework which accounted for differences between the Method 1 and Method 2 estimates of total Chinook encounters in mark-selective Chinook salmon fisheries. We have shown that both methods are subject to inherent biases which result in Method 1 generally overestimating and Method 2 generally underestimating the true total number of encounters. These biases are a result of violations of a major assumption associated with each method. Specifically:

- For Method 1, the assumption that anglers accurately report the number of Chinook salmon that they release.
- For Method 2, the assumption that anglers keep all legal-size, marked Chinook that they catch.

There is indirect and direct evidence showing that these assumptions have been violated to varying degrees in all mark-selective fisheries conducted in the marine waters of Puget Sound and the Strait of Juan de Fuca that have been surveyed to date.

For Method 1, the framework which best explains the differences between M1 and M2 estimates leads us to conclude that M1 usually overestimates the total number of Chinook encounters. Under this framework, we expect the magnitude of the overestimate, and consequently the difference between the M1 and M2 estimates (DIFF), to be a function of angler effort in the fishery and the average number of salmon released per angler in the fishery (ASRPAT). The data and analyses we presented demonstrate that DIFF is a function of effort, especially for summer selective fisheries, and ASRPAT.

Under this framework, we expect there to be little difference between the estimates when there is relatively low effort and the average number of salmon released per angler trip is relatively low. We expect intermediate values for DIFF when effort is relatively low but ASRPAT is relatively high or when effort is relatively high but ASRPAT is relatively low. Finally, we expect to observe the largest differences between the two methods when both angler effort and ASRPAT are relatively high.

To characterize this framework in more detail, we examined the estimates from the 44 area/month or season/year strata that we had estimates for (**Appendix Tables A1, A2**, **B1**, and **B2**) relative to the expected results as described above. We used a simplistic approach for classifying each of the 44 estimates as to effort level (low or high) and ASRPAT value (low or high). First, we ranked the 44 estimates from lowest to highest based on effort (average number of angler trips per day open). We categorized the 22 lowest effort estimates as low effort and the 22 highest estimates as high effort. We then did the same thing based on ASRPAT. We then calculated the mean DIFF and RATIO for the four categories. The results are summarized in **Table 3** below.

Table 3. Comparisons of mean DIFF and RATIO for four categories of relative effort and average number of salmon released per angler trip.

RELATIVE		Sample	Method 1 – Method 2 (DIFF)			Method 1/ Method 2 (RATIO)		
Effort	ASRPAT[a]	Size	Mean	St. Error	RPSE	Mean	St. Error	RPSE[b]
LOW	LOW	9	-5.78	22.971	397%	0.994	0.0979	10%
LOW	HIGH	13	374.38	255.535	68%	2.755	0.6274	23%
HIGH	LOW	13	1,025.23	548.248	53%	1.238	0.1254	10%
HIGH	HIGH	9	4,491.67	782.912	17%	1.820	0.1614	9%

[a]ASRPAT = Average Number of Salmon Released per Angler Trip

[b]RPSE = Relative percent standard error = (Standard Error /Mean) x 100%.

Table 3 demonstrates that the data support our framework expectations. When both effort and ASRPAT are low, there is very little difference between the M1 and M2 estimates (average difference less than 6 fish and RATIO ≈ 1.0). When effort is low but ASRPAT is high, the average difference in number of fish is not particularly large (≈ 400 fish) but the average relative difference between the M1 and M2 estimates is the largest for any of the categories (2.8). However, the relative percent standard error (23%) was more than twice that of the other categories. When effort is relatively high but ASRPAT is low, the average difference in number of fish exceeds 1,000 and the M1 estimate is, on average, 20% greater than the M2 estimate. Finally, when effort and ASRPAT are both relatively high, the average difference between the estimates is greatest (≈ 4,500 fish) and the M1 estimate is, on average, 80% greater than the M2 estimate.

Given that both estimators attempt to quantify the same attribute of selective fisheries, this qualitative framework may be useful for interpreting bias in total encounters estimates. For Method 2, the data demonstrate that the intentional release of legal-size, marked Chinook does occur. A model was presented which also accounts for the unintentional release of LSM Chinook. In combination with the model, the available data indicate that it is important to include the unintentional release of LSM Chinook when considering the bias of the Method 2 estimate. The available data indicate that the overall release rate of LSM Chinook (both intentional and unintentional) is relatively constant across selective fisheries and years and is in the 12-13% range.

If the Method 2 estimates of encounters were "corrected" to account for the bias resulting from the release of LSM Chinook, and this correction accounted for most of, if not all, the bias in the M2 estimates, this would provide a "best" estimate of total Chinook encounters. Because the Method 2 bias is relatively constant, we would expect similar relationships between the difference in M1 and "true" encounters (i.e., bias-corrected Method 2) and fishery attributes, i.e., the patterns of association described in **Table 3** apply to a DIFF analog computed from Method 1 estimates and the "true" number of encounters. Method 1 would provide fairly accurate estimates of total encounters in low effort fisheries where the average number of salmon released per angler is low and the Method 1 estimates would be expected to greatly overestimate the "true" number of encounters in selective fisheries with relatively high effort and high ASRPAT values. This result may be useful for modeling and accounting for bias in M1 estimates in cases where a M2-type alternative is unavailable.

While we focused on estimator bias in our review, precision is an aspect of parameter estimation that warrants additional discussion. In particular, it is evident from Figure 2 that the statistical precision of the M1 estimates was generally greater than it was for M2 estimates. This was especially apparent in those cases where M2 estimates exceeded M1 values (e.g., there were three occurrences in the estimates where, contrary to the framework previously described, M2 exceeded M1 estimated encounters by more than a trivial amount [> 500 fish]) but also occurred in other instances. To appropriately compare the precision of two biased estimators, however, Cochran (1977) recommends using the mean squared error (MSE) calculated as:

$$(7)\quad \text{MSE}\ (E) = \text{Variance}\ (E) + \text{Bias}\ (E)^2.$$

The coefficient of variation (CV) of the estimate (E) can then be calculated as the square root of MSE divided by E. We calculated the coefficients of variation for Method 2 bias-corrected estimates using a release rate of 13% for legal-size, marked Chinook. These were compared to CVs for Method 1 bias-corrected estimates using a range of release exaggeration rates from 20 to 50%. A release exaggeration rate of about 28% provided estimates with comparable CVs to Method 2 estimates for summer selective fisheries and a release exaggeration rate of about 42% provided estimates with comparable CVs to Method 2 estimates for winter selective fisheries. The results are summarized in **Table 4** below.

Table 4. Comparisons of coefficients of variation[a] (CV) for Method 1 estimates with a 28% and 42% release exaggeration rate and Method 2 estimates with a 13% release rate of legal-size, marked (LSM) Chinook.

CV of Total Encounters Estimate	Method 1 Rel. Exagg. Rate = 28%		Method 1 Rel. Exagg. Rate = 42%		Method 2 LSM Release Rate = 13%	
	Summer	Winter	Summer	Winter	Summer	Winter
Average	20.8%	28.7%	28.8%	39.0%	20.5%	38.4%
Median	20.4%	28.2%	28.8%	39.5%	18.8%	32.8%
Minimum	15.3%	18.4%	19.6%	25.2%	15.6%	20.7%
Maximum	26.3%	39.6%	35.0%	51.4%	33.3%	90.4%

[a] Coefficient of variation for the square root of the mean squared error of the estimated encounters calculated using equation 7 divided by the estimate of total encounters.

This demonstrates that when bias is accounted for in the calculation of the mean squared error, the precision of the estimates from the two methods is comparable for plausible release exaggeration rates for Method 1 when compared to Method 2 estimates using a 13% release rate for LSM Chinook.

SUMMARY AND CONCLUSIONS

Comparison of Method 1 and Method 2 Estimates of Total Chinook Encounters

We compared Method 1 and Method 2 estimates of total Chinook encounters for 44 discrete time/area/year strata in which Chinook selective fisheries were conducted in the marine waters of Puget Sound and the Strait of Juan de Fuca. The estimates included both summer (May through September) and winter (October through April) fisheries. Summer selective fisheries occurred in WDFW catch areas 5, 6, 9, 10, and 11 between 2003 and 2007. Winter selective fisheries occurred in WDFW catch areas 8-1 and 8-2 between 2005 and 2007.

Differences (M1-M2) between M1 and M2 estimates of total Chinook encounters ranged from -107 to 7,963 encounters for summer selective fisheries (mean = 3,073) and ranged from -1,903 to 4,049 encounters for winter selective fisheries (mean = 336). The M1 estimate was greater than the M2 estimate 73% of the time across all fisheries analyzed.

About 45% of the time the difference between the estimates exceeded 1,000 fish. Although in many cases the two estimates were not significantly different in a statistical sense, the often large difference in numbers is a management concern due to the uses of these data in management. Specifically, total mortality estimates are needed for abundance forecasting, cohort run reconstruction, catch accounting, and preseason management model evaluation.

Conclusion 1: The differences between the Method 1 and Method 2 estimates of total Chinook encounters in selective fisheries are often large enough to be of concern for their use in existing management processes. A single, "best estimate" of total encounters is needed.

Comparison of Summer and Winter Selective Fishery Characteristics and Associations between Fishery Metrics and M1/M2 Differences

We used metrics describing selective fisheries to compare the summer and winter fisheries and examined the relationships between these metrics and the difference between the M1 and M2 estimates. We found that there are:

- Seasonal differences in fishery characteristics: We show that, on average, summer selective fisheries have higher angler participation (effort) and lower salmon release rates than winter selective fisheries.
- Seasonal differences in M1 and M2 differences: Absolute differences in M1 and M2 estimates (DIFF) were greater and more variable (on a period-to-period level) for summer compared to winter fisheries; in contrast, relative differences in M1 and M2 estimates (RATIO) were similar for both seasons but more variable for winter compared to summer.
- Significant relationships between M1 and M2 differences and some fishery metrics: Absolute differences in estimates (DIFF) were positively correlated with both fishing effort and salmon release rates but were more strongly related to effort

for summer fisheries and more strongly correlated to release rates for winter fisheries. For the regression model fitting and prediction analyses, variance in DIFF estimates across periods and/or areas was best explained by the effort metric for summer fisheries; for winter, the best DIFF regression model included the salmon release-rate metric. Finally, though the general trends in association between the RATIO variable and fishery predictors were similar to those seen for DIFF, correlation and regression analyses were less informative for this response.

Conclusion 2: The primary factors influencing the size of the difference between the M1 and M2 estimates are angler effort in the fishery and the average number of salmon released per angler trip.

Bias Potential

For Method 1, we found evidence suggesting that some combination of digit bias and prestige bias contributes to M1 over-estimating the true number of Chinook encounters. E.g., in time/area/year strata with the most pronounced evidence of digit bias (when reported frequencies of release of seven or more salmon are common), we also find the largest differences between the M1 and M2 estimates. There was one previous study based in Puget Sound that indicated that anglers overestimate the number of salmon they release, on average, by about 40%.

For Method 2, we reviewed evidence indicating that LSM Chinook release occurs on both an intentional and unintentional basis. On a seasonal level, anglers intentionally release LSM Chinook at a higher rate in winter compared to summer selective fisheries (winter = 7.6%, summer = 4.3%); however, the reverse pattern was observed for the unintentional LSM Chinook release component (summer = 7.8%, winter = 4.3%). In combination, these two factors result in a 12-13% underestimate of actual (true but unknown) encounters by M2 for both seasons. Though there are several caveats that accompany this result, it seems to be a reasonable and replicable (and conservative) estimate of bias due to LSM release behavior.

Conclusion 3: There is clear potential for bias in both Method 1 and Method 2 estimates. For Method 2, we have data collected during recent Chinook selective fisheries that allows us to estimate the magnitude of this bias. There are no new data available to estimate the magnitude of the Method 1 bias; the only data available were collected in 1997 and 1998 and were not from Chinook selective fisheries.

Bias Correction

For Method 1, the digit bias correction procedure (the Beaman-Vaske method) did not greatly change the estimated number of salmon released per angler and, therefore, did not effectively address the expected bias in Method 1. For multiple reasons, the Beaman-Vaske method does not appear promising as a means for bias correction on a practical level. Correcting M1 estimates at the fishery-total level to account for the bias caused by anglers over-reporting the number of salmon they have released (i.e. due to a prestige bias), on average, is not practicable either due to the lack of relevant data on this behavior in Chinook selective fisheries.

For Method 2, a bias correction method was proposed that is based on data collected from Chinook selective fisheries. The method accounts for both the intentional and unintentional release of legal-size, marked Chinook salmon by anglers.

At the extremes, the parameter grid search indicated that for the original M1 estimates to have been perfectly accurate (and therefore all M1-M2 difference to have been due to M2 bias), anglers would have had to release an unrealistically high percentage (30-40%) of all of the LSM Chinook that they encountered. Conversely, for all M1-M2 difference to have been a result of M1 bias, anglers would have had to report (during their interviews) releasing nearly double (>80%) the number of Chinook that they actually released, on average. Given that these results are based on the extremes (either 0% M1 bias or 0% M2 bias), a more likely scenario demonstrated by the grid search that is consistent with field and/or literature data is that anglers release 10-16% of the LSM Chinook they encounter (intentional or unintentional) and exaggerate the number of salmon they actually release by about 50%, on average.

Conclusion 4: Currently, bias correction methods for Method 1 are not practicable. A bias-correction procedure for Method 2 estimates that incorporates both the intentional and unintentional release of legal-size, marked Chinook salmon by anglers is supported by the existing data and analyses.

RECOMMENDATIONS

It was demonstrated that both Method 1 and Method 2 estimates of total Chinook encounters have the potential for bias. Based on our analyses of available data, we recommend Method 2 estimates with correction for the release of legal-size marked Chinook as the preferred method for estimating total Chinook encounters in mark-selective Chinook fisheries. This recommendation is based on the following considerations:

- The bias of Method 1 estimates of total Chinook encounters was shown to be a function of angler effort in a fishery and the average number of salmon released per angler. Because it is not constant, it is difficult to estimate Method 1 bias. There are no data available from the most recently conducted selective fisheries (fisheries conducted since 2003) that allow us to specifically estimate the Method 1 bias.
- A framework was developed that allows us to estimate the bias of the Method 2 estimates of total Chinook encounters using data collected dockside during the fisheries and from associated test fisheries. Specifically, we estimated the release rate (both intentionally and unintentionally) of legal-size, marked Chinook by anglers.
- Although there were seasonal (summer|winter) differences between the two components that are used to estimate the LSM Chinook release rate by anglers in a selective fishery, when combined these two components result in a fairly consistent estimate of the release rate of LSM Chinook from fishery-to-fishery and year-to-year.

Thus, we recommend using an assumed LSM Chinook release rate of 13% for anglers participating in mark-selective fisheries. Given the precision of all data types used to derive this number, the use of an adjustment of any higher precision (i.e., the estimated grand mean of 12.7%) than ±1% is unwarranted. Using this rate, a bias-corrected estimate of total Chinook encounters could be obtained under Method 2 using[11]:

(7) Bias-Corrected M2 = Original M2 Estimate / (1-0.13)
= Original M2 Estimate / (0.87)

This correction for bias should be applied to all Method 2 estimates that are produced by Murthy-type creel surveys in mark-selective fisheries conducted in the marine waters of the Strait of Juan de Fuca and Puget Sound. In addition, it may be possible to use this bias correction in cases when an estimate of the total number of LSM Chinook harvested is obtained by means other than the Murthy-type creel survey approach. For example, it may be possible to generate an estimate of total Chinook encounters using the Method 2 procedure (*with bias correction*) when estimates of total Chinook harvest resulting the WDFW Catch Record Card (CRC) survey are coupled with field estimates of relative LSM Chinook abundance (from VTRs or test fishing).

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[11] An estimate of the variance for bias-corrected M2 encounters can be obtained from:

var(Bias-Corrected M2) = var(Original M2 Estimate) / $[(0.87)^2]$

Given that this proposed modification does not include an estimate of the variance of the bias-correction factor, this will be a minimum estimate of the true variance of Bias-Corrected M2.

Recommended Future Research and Data Collection

1. If the proposed 13% correction is found to be acceptable, past estimates of total Chinook encounters should be revised and provided in a historical data appendix in a future post-season report.
2. Means for reducing the variance of the Method 2 estimates without expanding sampling efforts should be explored (e.g., evaluate variance contributions from dockside and test fishing components).
3. Sampling should continue in mark-selective fisheries so that the data needed to estimate LSM Chinook release rates are periodically obtained. This will enable routine calibration of the proposed bias correction, which may be necessary if/when major changes occur in either fishery regulations (e.g., changes in size limits, increasing of bag limits, etc.) or fish populations (e.g., persistent shifts in size/age structure) that may influence this parameter's value. Also, where and when it is feasible, fishery-total estimates of LSM Chinook releases should be produced and evaluated relative to the proposed M2 bias correction.
4. As additional CRC estimates of total Chinook harvest become available for the selective fisheries reviewed in this report, estimates of total Chinook encounters generated using the intensive Murthy approach should be compared with those derived from the CRC system. In particular, such an analysis should emphasize understanding the utility of the bias-corrected M2 estimator for generating unbiased estimates of total Chinook encounters with CRC harvest data as the starting point.
5. In fisheries characterized by a large catch-and-release component (mark-selective, salmon, or otherwise), we recommend that estimates of total encounters generated from angler interviews be interpreted cautiously. This recommendation is particularly relevant to situations where apparent encounter rates are high.

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Appendix A. Supplemental Data and Supporting Figures

Table A1. Comparison of Method 1 and Method 2 estimates of total Chinook encounters for summer selective fisheries conducted in Puget Sound marine areas, 2003 – 2007.

Area	Year	Season or Statistical Month	Days Open	Effort (angler trips)	Legal-Marked Harvest	Estimated Encounters Method 1	Estimated Encounters Method 2	M1-M2 (DIFF)	M1 / M2 (RATIO)
5	2003	July 5 - August 3	30	19,398	2,251	15,950	11,424	4,526	1.396
5	2004	July 1 - August 8	39	25,174	2,706	15,321	9,527	5,794	1.608
5	2005	July 1 - August 10	41	30,115	1,520	7,471	5,206	2,265	1.435
5	2006	July 1 - Aug. 14, 18 - 21	49	23,177	3,105	11,909	8,812	3,097	1.351
5	2007	July 1 - Aug. 4 & Aug. 9	36	18,830	2,969	11,317	7,663	3,654	1.477
6	2003	July 5 - August 3	30	5,195	941	2,712	2,211	501	1.227
6	2004	July 1 - August 8	39	4,251	669	2,088	1,434	654	1.456
6	2005	July 1 - August 10	41	3,971	404	1,045	1,152	-107	0.907
6	2006	July 1 - Aug. 14, 18 - 21	49	3,077	338	683	768	-85	0.889
6	2007	July 1 - Aug. 4 & Aug. 9	36	3,221	715	1,614	1,087	527	1.485
9	2007	July 16 - July 31	16	18,334	5,094	15,546	7,657	7,889	2.030
10	2007	July 16 - July 28	13	8,444	1,469	8,466	5,336	3,130	1.587
11	2007	June 1 - July 1	31	8,298	753	4,369	2,695	1,674	1.621
11	2007	July 2 - August 5	35	24,076	2,874	12,336	5,556	6,780	2.220
11	2007	August 6 - Sep. 2	28	37,850	6,190	20,380	12,417	7,963	1.641
11	2007	Sep. 3 - Sep. 30.	28	8,734	375	2,520	1,614	906	1.561
			Average	15,134	2,023	8,358	5,285	3,073	1.493
			Minimum	3,077	338	683	768	-107	0.889
			Maximum	37,850	6,190	20,380	12,417	7,963	2.220

Table A2. Comparison of Method 1 and Method 2 estimates of total Chinook encounters for winter selective fisheries conducted in Puget Sound marine areas, 2005 – 2007.

Area	Year	Statistical Month	Days Open	Effort (angler trips)	Legal-Marked Harvest	Estimated Encounters Method 1	Estimated Encounters Method 2	M1-M2 (DIFF)	M1 / M2 (RATIO)
8-1	2005	October 1 - 30	30	1,154	36	376	418	-42	0.900
8-1	2005	Oct. 31 - Nov. 27	28	350	39	144	244	-100	0.590
8-1	2005	Nov. 28 - Dec. 31	34	427	43	218	188	30	1.160
8-1	2006	January 1 - 29	29	327	38	183	264	-81	0.693
8-1	2006	Jan. 30 - Feb. 26	28	640	97	347	298	49	1.164
8-1	2006	Feb. 27 - Mar. 26	28	702	31	169	190	-21	0.889
8-1	2006	Mar. 27 - Apr. 30	34	376	19	85	64	21	1.328
8-2	2005	October 1 - 30	30	2,940	36	489	1,105	-616	0.443
8-2	2005	Oct. 31 - Nov. 27	28	353	26	104	134	-30	0.776
8-2	2005	Nov. 28 - Dec. 31	34	501	103	398	276	122	1.442
8-2	2006	January 1 - 29	29	586	151	620	430	190	1.442
8-2	2006	Jan. 30 - Feb. 26	28	1,293	196	803	699	104	1.149
8-2	2006	Feb. 27 - Mar. 26	28	1,285	82	416	463	-47	0.898
8-2	2006	Mar. 27 - Apr. 30	34	1,561	142	444	504	-60	0.881
8-1	2006	October 1 - 28	28	829	44	2,483	972	1,511	2.555
8-1	2006	Oct. 29 - Dec. 3	36	195	11	387	121	266	3.198
8-1	2006	Dec. 4 - Jan. 1	29	310	47	966	499	467	1.936
8-1	2007	January 2 - 28	27	287	19	529	173	356	3.058
8-1	2007	Jan. 29 - Feb. 25	28	405	22	982	162	820	6.062
8-1	2007	Feb. 26 - Apr. 1	35	762	65	1,676	203	1,473	8.256
8-1	2007	April 2 - April 29	28	667	69	1,162	289	873	4.021
8-2	2006	October 1 - 28	28	2,186	58	6,770	2,721	4,049	2.488
8-2	2006	Oct. 29 - Dec. 3	36	392	28	1,110	1,966	-856	0.565
8-2	2006	Dec. 4 - Jan. 1	29	655	108	2,592	2,410	182	1.076
8-2	2007	January 2 - 28	27	655	117	1,718	3,621	-1,903	0.474
8-2	2007	Jan. 29 - Feb. 25	28	1,121	102	2,092	1,052	1,040	1.989
8-2	2007	Feb. 26 - Apr. 1	35	1,334	229	2,939	2,491	448	1.180
8-2	2007	April 2 - April 29	28	1,505	125	1,827	672	1,155	2.719
			Average	850	74	1,144	808	336	1.905
			Minimum	195	11	85	64	-1,903	0.443
			Maximum	2,940	229	6,770	3,621	4,049	8.256

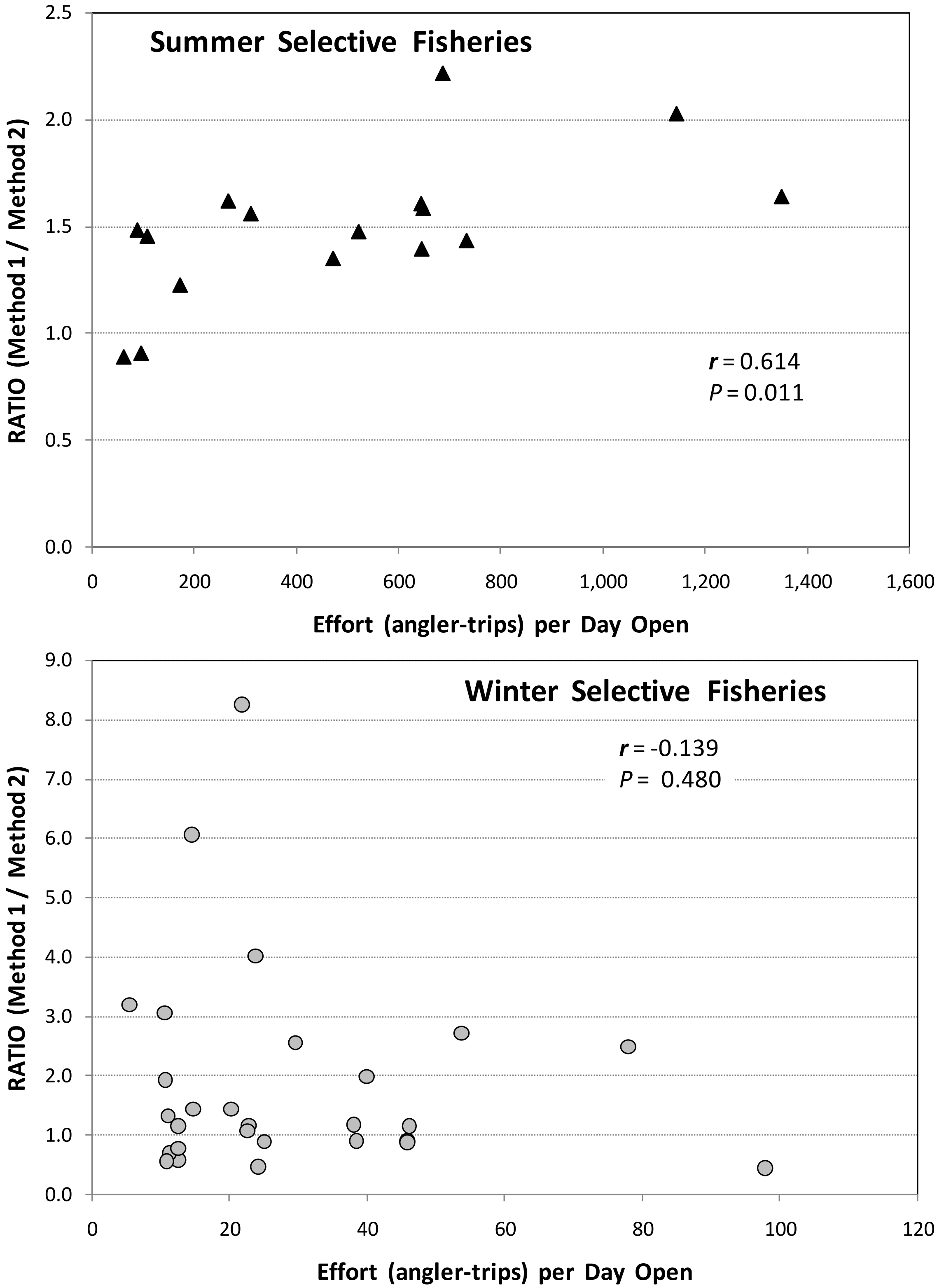

Figure A1. Scatter plot of effort (angler trips per day open) and RATIO (Method 1/Method 2 total Chinook encounters estimates) for summer and winter selective fisheries.

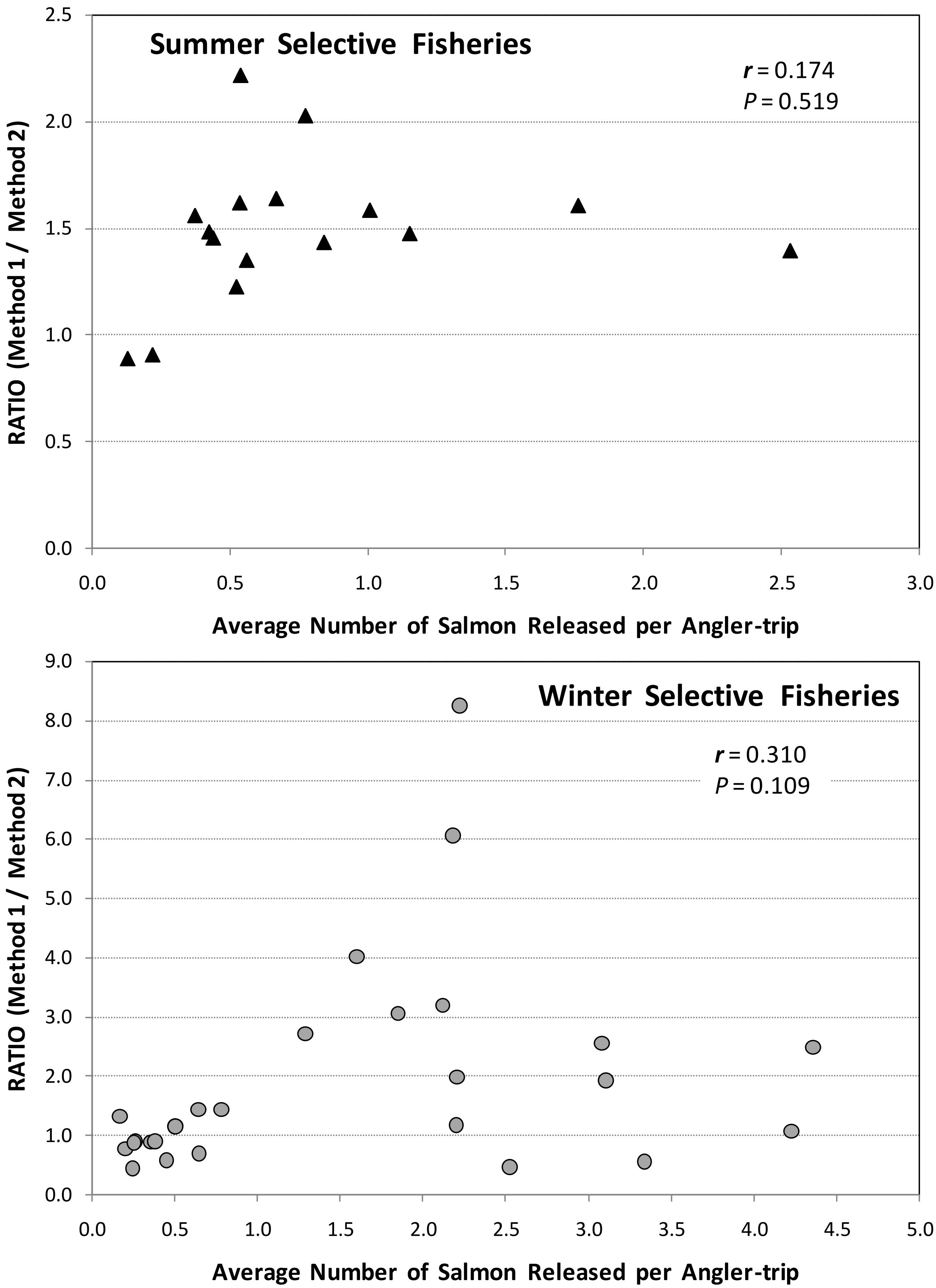

Figure A2. Scatter plot of the average number of salmon released per angler trip and RATIO (Method 1/Method 2 total Chinook encounters estimates) for summer and winter selective fisheries.

Appendix B. Description of the Interview Dataset and Associated Metrics

WDFW's Puget Sound Sampling Unit interviews anglers at boat access points (i.e., public ramps, marinas, and/or other launch sites) as part of an intensive selective fishery monitoring program and for their routine baseline sampling efforts[12]. These data are collected on a boat-by-boat basis (i.e., the catch and release data for all anglers in a boat were recorded as a single record) and housed in year-specific Baseline databases that WDFW maintains. In support of the Method 1 and Method 2 comparison, we queried the baseline databases for individual records logged during all years and date ranges that Areas 5, 6, 8-1, 8-2, 9, 10, and 11 were open under mark-selective Chinook harvest regulations between the summers of 2003 and 2007. Further, we constrained queries to include boat-based fishing methods (i.e., charter [code = 1] or kicker [code = 2]) and salmon-directed (code = 1) or salmon-plus-marine-fish-directed (code = 3) trips only. These constraints were used in order to create a raw-interview dataset consistent with what is typically used to derive in-season and post-season estimates of selective fishery parameters. For this analysis, year-specific query results were combined into a single multi-year selective-only boat interview database.

We calculated four metrics from these data, two of which were binary, and used averages to characterize angler success in each selective fishery. All metrics focused on the number of *salmonids* released or encountered and were not calculated using only Chinook release and encounter data reported by anglers. The reason for this was the prevalence of "unidentified" salmon reported as released by anglers and the possibility that anglers could misidentify the species of salmon that were released. Also, we assumed that the accuracy for the number of Chinook that anglers reported as released during a trip was not solely a function of the number of Chinook that were encountered and released but all salmon that were encountered and released.

Two of the metrics were calculated using the total number of salmon encountered. The number of salmon encountered was calculated as the sum of the salmon harvested (retained and verified at the dock during the interview) and those salmon reported as released. Salmon species included in the salmon harvested portion of the calculations included Chinook, coho salmon (*Oncorhynchus kisutch*), pink salmon (*O. gorbuscha*), chum salmon (*O. keta*), sockeye salmon (*O. nerka*), and steelhead trout (*O. mykiss*). In addition to the salmon species listed previously, trout (primarily cutthroat [*O. clarkii clarkii*]) were included in calculating the number of salmon released because of the possibility of species misidentification. Trout were reported as being released in only 9 of the 37,088 boat interviews (0.024%) used in these analyses. All non-binary metrics were calculated per angler trip, i.e., the total number of salmon encounters and the total number of salmon released reported by each boat interviewed were divided by the number of anglers fishing in the boat.

[12] Emphasis studies associated with mark-selective fisheries are built around a probability-proportional-to-size sampling scheme and designed to yield in-season estimates of catch and effort. Baseline sampling is opportunistic in nature and is done to provide supplemental information (e.g., catch per unit effort) for CRC-based catch and effort estimation.

For each fishery and estimation period[13] we calculated:

1. average number of salmon released per angler trip,
2. average number of salmon encountered per angler trip,
3. the percentage of boat trips releasing one or more salmon, and
4. the percentage of boat trips encountering one or more salmon.

Table B1 and **B2** summarize these data for the summer and winter selective fisheries, respectively.

[13] Estimation periods were either season or statistical month: see Appendix Tables A1 and A2 for descriptions.

Table B1. Summary of the metrics calculated from the boat interview data collected during creel surveys and the baseline sampling program for summer selective fisheries conducted in Puget Sound marine areas, 2003 – 2007.

CRC Area	Season	Period	Sample Size	Salmon Releases per Angler Trip			Salmon Encounters per Angler Trip		
				Mean	SE[a]	% Rel. SE[b]	Mean	SE	% Rel. SE
5	2003	Season	1,725	2.533	0.081	3.2%	3.313	0.088	2.7%
5	2004	Season	2,501	1.764	0.049	2.8%	2.318	0.055	2.4%
5	2005	Season	3,118	0.842	0.031	3.6%	1.545	0.039	2.5%
5	2006	Season	2,581	0.561	0.026	4.7%	0.762	0.030	4.0%
5	2007	Season	2,004	1.153	0.046	4.0%	2.029	0.057	2.8%
6	2003	Season	1,161	0.524	0.037	7.1%	0.824	0.046	5.6%
6	2004	Season	1,080	0.440	0.029	6.6%	0.646	0.037	5.7%
6	2005	Season	889	0.219	0.020	9.2%	0.405	0.028	7.0%
6	2006	Season	785	0.129	0.014	11.2%	0.262	0.022	8.4%
6	2007	Season	888	0.424	0.035	8.2%	0.921	0.049	5.3%
9	2007	Season	2,212	0.774	0.027	3.5%	1.082	0.032	2.9%
10	2007	Season	1,141	1.008	0.052	5.1%	1.311	0.056	4.3%
11	2007	June	1,502	0.536	0.030	5.7%	0.668	0.033	4.9%
11	2007	July	3,540	0.539	0.021	4.0%	0.759	0.023	3.1%
11	2007	August	4,452	0.668	0.027	4.1%	1.096	0.030	2.8%
11	2007	September	1,092	0.373	0.033	8.8%	0.640	0.039	6.1%
Area 11 Season Totals			10,586	0.576	0.015	2.5%	0.875	0.016	1.9%

[a] Standard error.
[b] Percent relative standard error (SE/mean).

Table B2. Summary of the metrics calculated from the boat interview data collected during creel surveys and the baseline sampling program for <u>winter</u> selective fisheries conducted in Puget Sound marine areas, 2005 – 2007.

CRC Area	Season	Period	Sample Size	Salmon Releases per Angler Trip			Salmon Encounters per Angler Trip		
				Mean	SE[a]	% Rel. SE[b]	Mean	SE	% Rel. SE
81	2005-06	October	207	0.264	0.053	19.9%	0.529	0.061	11.6%
81	2005-06	November	60	0.453	0.102	22.5%	0.567	0.114	20.2%
81	2005-06	December	85	0.502	0.088	17.6%	0.606	0.102	16.9%
81	2005-06	January	74	0.651	0.116	17.8%	0.881	0.132	15.0%
81	2005-06	February	209	0.508	0.060	11.7%	0.677	0.072	10.6%
81	2005-06	March	109	0.361	0.074	20.6%	0.463	0.088	18.9%
81	2005-06	April	107	0.170	0.041	24.0%	0.221	0.048	21.7%
		Season Total	851	0.395	0.027	6.9%	0.559	0.032	5.7%
82	2005-06	October	852	0.248	0.021	8.5%	0.400	0.025	6.4%
82	2005-06	November	132	0.205	0.037	18.0%	0.292	0.047	16.0%
82	2005-06	December	138	0.644	0.100	15.5%	0.876	0.119	13.6%
82	2005-06	January	148	0.784	0.095	12.2%	1.063	0.107	10.1%
82	2005-06	February	430	0.504	0.040	7.8%	0.668	0.047	7.0%
82	2005-06	March	364	0.384	0.041	10.7%	0.488	0.046	9.4%
82	2005-06	April	387	0.258	0.031	12.0%	0.369	0.038	10.2%
		Season Total	2,451	0.367	0.016	4.2%	0.516	0.018	3.5%
81	2006-07	October	133	3.084	0.401	13.0%	3.194	0.404	12.7%
81	2006-07	November	26	2.122	0.529	24.9%	2.353	0.534	22.7%
81	2006-07	December	87	3.106	0.359	11.6%	3.212	0.362	11.3%
81	2006-07	January	130	1.853	0.188	10.2%	2.031	0.198	9.7%
81	2006-07	February	79	2.182	0.288	13.2%	2.307	0.295	12.8%
81	2006-07	March	129	2.224	0.260	11.7%	2.401	0.269	11.2%
81	2006-07	April	191	1.600	0.155	9.7%	1.744	0.163	9.4%
		Season Total	775	2.247	0.110	4.9%	2.393	0.113	4.7%
82	2006-07	October	641	4.361	0.219	5.0%	4.406	0.221	5.0%
82	2006-07	November	90	3.342	0.454	13.6%	3.474	0.468	13.5%
82	2006-07	December	232	4.230	0.347	8.2%	4.386	0.354	8.1%
82	2006-07	January	306	2.529	0.189	7.5%	2.727	0.198	7.3%
82	2006-07	February	267	2.208	0.168	7.6%	2.343	0.170	7.3%
82	2006-07	March	355	2.205	0.139	6.3%	2.405	0.144	6.0%
82	2006-07	April	449	1.290	0.111	8.6%	1.389	0.114	8.2%
		Season Total	2,340	2.907	0.087	3.0%	3.031	0.088	2.9%

[a] Standard error.
[b] Percent relative standard error (SE/mean).

Appendix C. Regression Model Evaluation Statistics

The three model evaluation statistics used to compare the regression models were (Abraham and Ledolter 1983): (1) mean percent error (MPE); (2) mean square error (MSE); and (3) mean absolute percent error (MAPE). These statistics were computed using a jackknife procedure (Efron and Tibshirani 1993). The jackknife procedure sequentially omits one observation from the regression model computations, computes a new regression model using the remaining data, predicts $\hat{Y}$ for the omitted observation using the independent variable for that observation and the new model, and compares the predicted $\hat{Y}$ to that observed for the observation omitted.

The three model comparison statistics are defined as follows:

(1) $$MPE = \frac{100}{n}\sum_{i=1}^{n}\frac{(Y_i - \hat{Y}_i)}{Y_i} = \frac{100}{n}\sum_{i=1}^{n}\frac{(Observed_i - Predicted_i)}{Observed_i}$$

(2) $$MSE = \frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n} = \frac{\sum_{i=1}^{n}(Observed_i - Predicted_i)^2}{n}$$

(3) $$MAPE = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{Y_i - \hat{Y}_i}{Y_i}\right| = \frac{100}{n}\sum_{i=1}^{n}\left|\frac{Observed_i - Predicted_i}{Observed_i}\right|$$

where

- n = the number of observations in the regression model,
- Y_i = the actual value of the dependent variable for the observation omitted from the model, and
- $\hat{Y}$ = the predicted value of the dependent variable using the value of the independent variable for the omitted observation and the new regression model estimated without the omitted observation.

The MPE statistic can be positively or negatively signed and should be a percentage close to zero. It is a general indication of whether the model tends to over predict (- MPE) or under predict (+ MPE). Smaller MSE and MAPE statistics indicate better fitting models.

The following describes the dependent and independent variables examined in the ordinary least squares regression analyses.

Dependent Variables

DIFF	=	The difference between the Method 1 and Method 2 estimates of total Chinook encounters. The natural logarithm of DIFF was also used.
RATIO	=	The Method 1 estimate divided by the Method 2 estimate of total Chinook encounters.

Independent Variables

***Variables Calculated from the Creel Survey Data*:**

Effort1	=	Angler effort for a fishery measured as total estimated angler trips.
Effort2	=	Angler effort for a fishery measured as estimated angler trips per day open.
LglHRV	=	The estimated harvest of legal-size, marked Chinook salmon by the fishery.
TotHRV	=	The estimated total harvest of Chinook salmon by the fishery (includes sublegal marked Chinook and unmarked Chinook).
HPUE1	=	The estimated total harvest (TotHRV) of Chinook salmon by the fishery per angler trip.
HPUE2	=	The estimated total harvest (TotHRV) of Chinook salmon by the fishery per day open.

***Variables Calculated from the Test Fishery Data*:**

PerL2K	=	The percent of Chinook encountered by the test fishery that were legal-size and marked. The arcsine transform of this percentage was also used.
PerSL	=	The percent of Chinook encountered by the test fishery that were sublegal size (both marked and unmarked). The arcsine transform of this percentage was also used.

***Variables Calculated from the Dockside Angler Interview Data*:**

RelPAT	=	The average number of salmon[14] released per angler trip.
EncPAT	=	The average number of salmon encountered per angler trip.
PerES	=	The percentage of the boats interviewed that encountered one or more salmon. The arcsine transform of this percentage was also used.
PerRS	=	The percentage of the boats interviewed that released one or more salmon. The arcsine transform of this percentage was also used.

[14] Salmon here means all salmonid species. See Appendix B.

Combined Independent Variables (index variables that are a product of two independent variables):

CmbIndex1	=	The product of LGLHRV and RelPAT.
CmbIndex2	=	The product of LGLHRV and EncPAT.
CmbIndex3	=	The product of Effort1 and RelPAT.
CmbIndex4	=	The product of Effort1 and EncPAT.
CmbIndex5	=	The product of Effort2 and RelPAT.
CmbIndex6	=	The product of Effort2 and EncPAT.

Appendix D. Supporting Test Fishery Length Distribution Data

Table D1. Proportion of marked Chinook encounters by the test fishery that were within ±2 inches (5 cm) of the legal size limit (22 in [56 cm]) for summer selective fisheries. The "20-22 in" and "22-24 in" categories are left-closed intervals (i.e., ≥x1 and < x2).

CRC Area	Year	Period	Sample Size	<20 in (<51 cm)	20-22 in (51-56 cm)	22-24 in (56-61 cm)	≥24 in (≥61 cm)
5	2003	Season	140	0.293	0.093	0.221	0.393
	2004	Season	71	0.183	0.127	0.127	0.563
	2005	Season	85	0.306	0.129	0.153	0.412
	2006	Season	103	0.087	0.175	0.204	0.534
	2007	Season	46	0.261	0.065	0.022	0.652
6	2003	Season	92	0.022	0.011	0.022	0.946
	2004	Season	76	0.013	0.039	0.026	0.921
	2005	Season	9	0.000	0.000	0.000	1.000
	2006	Season	4	0.000	0.000	0.000	1.000
	2007	Season	50	0.000	0.000	0.020	0.980
9	2007	Season	145	0.159	0.083	0.083	0.676
10	2007	Season	112	0.661	0.089	0.036	0.214
11	2007	Jun.	51	0.431	0.137	0.059	0.373
		Jul.	39	0.154	0.179	0.128	0.538
		Aug.	86	0.279	0.128	0.116	0.477
		Sept.	53	0.415	0.302	0.132	0.151
		Season	*229*	*0.323*	*0.179*	*0.109*	*0.389*

Table D2. Proportion of marked Chinook encounters by the test fishery that were within ±2 inches (5 cm) of the legal size limit (22 in [56 cm]) for winter selective fisheries. The "20-22 in" and "22-24 in" categories are left-closed intervals (i.e., >x1 and < x2).

CRC Area	Year	Period	Sample Size	<20 in (<51 cm)	20-22 in (51-56 cm)	22-24 in (56-61 cm)	>24 in (>61 cm)
8-1	2005-06	Oct.	32	0.844	0.031	0.000	0.125
		Nov.	23	0.478	0.217	0.130	0.174
		Dec.	33	0.515	0.091	0.091	0.303
		Jan.	60	0.667	0.050	0.083	0.200
		Feb.	48	0.500	0.021	0.104	0.375
		Mar.	52	0.692	0.038	0.038	0.231
		Apr.	14	0.429	0.071	0.071	0.429
		Season	*262*	*0.615*	*0.061*	*0.073*	*0.252*
	2006-07	Oct.	363	0.865	0.061	0.044	0.030
		Nov.	30	0.800	0.033	0.067	0.100
		Dec.	215	0.805	0.065	0.084	0.047
		Jan.	262	0.718	0.126	0.069	0.088
		Feb.	148	0.615	0.115	0.081	0.189
		Mar.	64	0.406	0.109	0.141	0.344
		Apr.	70	0.571	0.057	0.057	0.314
		Season	*1152*	*0.743*	*0.085*	*0.069*	*0.103*
8-2	2005-06	Oct.	25	0.880	0.080	0.000	0.040
		Nov.	26	0.615	0.115	0.115	0.154
		Dec.	23	0.348	0.000	0.130	0.522
		Jan.	30	0.333	0.133	0.200	0.333
		Feb.	33	0.515	0.061	0.182	0.242
		Mar.	15	0.467	0.200	0.200	0.133
		Apr.	31	0.484	0.161	0.097	0.258
		Season	*183*	*0.519*	*0.104*	*0.131*	*0.246*
	2006-07	Oct.	320	0.944	0.028	0.016	0.013
		Nov.	70	0.929	0.057	0.014	0.000
		Dec.	145	0.876	0.069	0.028	0.028
		Jan.	102	0.804	0.108	0.049	0.039
		Feb.	42	0.833	0.048	0.000	0.119
		Mar.	54	0.630	0.204	0.093	0.074
		Apr.	82	0.683	0.085	0.110	0.122
		Season	*815*	*0.860*	*0.066*	*0.036*	*0.038*

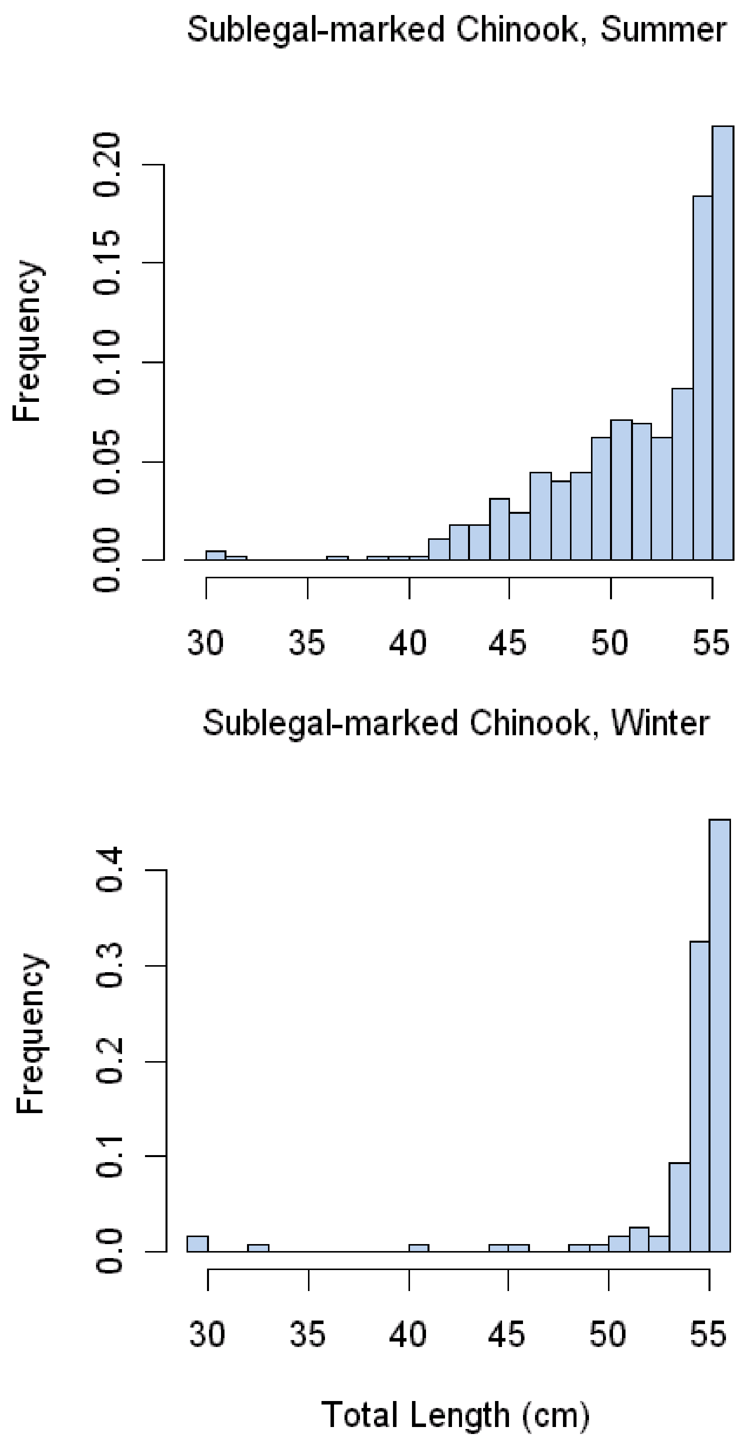

Figure D1. Length-frequency distributions for sublegal-marked Chinook retained in summer and winter selective fisheries.

Appendix E. Supporting Tables and Figures for Bias-Correction Methods

Table E1. Data from Noviello (1998) that estimates the M1 bias-correction parameter *R*. Excluding the "Bias measures" portion, this table is an adaptation of Table 2 in Noviello (1998).

		On the Water ("Truth")					At the Dock					Bias measures	
Fishery (Area / regime)	**Month(s)**	**Harvest *h***	**Released *r***	**Encounters**	**Percent Released**	***r*:*h*[a]**	**Harvest *h***	**Released *r***	**Encounters**	**Percent Released**	***r*:*h*[a]**	**Exag. Rate[b]**	**OW:DS[c]**
Area 5 Pinks Only	Aug. 1997	73	80	153	52%	1.10	472	482	954	51%	1.02	-7%	1.073
Area 5 Pink and Coho	Aug-Sept. 1997	104	39	143	27%	0.38	8,233	4,731	12,964	37%	0.57	53%	0.653
Area 4 Chinook and Pinks	July 1997	18	66	84	79%	3.67	154	1,459	1,613	91%	9.47	158%	0.387
Area 4 Pinks Only	Aug. 1997	3	11	14	79%	3.67	480	845	1325	64%	1.76	-52%	2.083
Area 4 Coho and Pinks	Aug. 1997	36	14	50	28%	0.39	589	531	1120	47%	0.90	132%	0.431
Area 8 Pinks and Coho	Aug.-Sept. 1997	91	11	102	11%	0.12	345	329	674	49%	0.95	689%	0.127
Area 10 All Salmon	Sept. 1998	65	21	86	24%	0.32	134	184	318	58%	1.37	325%	0.235

[a] Number released/number harvested.

[b] Exaggeration rate = (1/R)-1 as defined in the text.

[c] OW:DS = the ratio of *r*:*h* for on the water observations to the ratio of *r*:*h* for on the dockside observations: this is equivalent to *R* in equation 5.

Table E2. Results of the M1|M2 bias correction parameter grid search. Rows correspond to levels of LSM release rates, columns correspond to exaggeration rates, and cell values are equivalent to |Σ(M1-M2)|/1,000 (across fisheries). Parameter combinations yielding minimal Σ DIFF (<10,000 over all fisheries) are highlighted in gray.

LSM release rate (combined intentional & unintentional)	Proportional exaggeration rate (i.e., 1/R -1)															
	-0.5	**-0.4**	**-0.3**	**-0.2**	**-0.1**	**0**	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
0.00	187.6	144.6	113.9	90.8	72.9	58.6	46.8	37.1	28.8	21.7	15.6	10.2	5.5	1.2	2.5	5.9
0.01	186.5	143.5	112.8	89.7	71.8	57.5	45.8	36.0	27.7	20.6	14.5	9.1	4.4	0.2	3.6	7.0
0.02	185.4	142.4	111.7	88.6	70.7	56.4	44.7	34.9	26.6	19.5	13.4	8.0	3.3	1.0	4.7	8.1
0.03	184.2	141.2	110.5	87.5	69.6	55.3	43.5	33.8	25.5	18.4	12.3	6.9	2.1	2.1	5.9	9.2
0.04	183.1	140.1	109.4	86.4	68.4	54.1	42.4	32.6	24.3	17.2	11.1	5.7	1.0	3.2	7.0	10.4
0.05	181.9	138.9	108.2	85.2	67.3	52.9	41.2	31.4	23.2	16.1	9.9	4.6	0.2	4.4	8.2	11.6
0.06	180.7	137.7	107.0	84.0	66.1	51.7	40.0	30.2	22.0	14.9	8.7	3.4	1.4	5.6	9.4	12.8
0.07	179.5	136.5	105.8	82.7	64.8	50.5	38.8	29.0	20.7	13.6	7.5	2.1	2.6	6.8	10.6	14.0
0.08	178.2	135.2	104.5	81.5	63.6	49.2	37.5	27.7	19.5	12.4	6.2	0.9	3.9	8.1	11.9	15.3
0.09	177.0	134.0	103.3	80.2	62.3	48.0	36.2	26.5	18.2	11.1	5.0	0.4	5.1	9.4	13.1	16.5
0.10	175.7	132.7	101.9	78.9	61.0	46.7	34.9	25.2	16.9	9.8	3.7	1.7	6.5	10.7	14.4	17.8
0.11	174.3	131.3	100.6	77.6	59.7	45.3	33.6	23.8	15.6	8.5	2.3	3.1	7.8	12.0	15.8	19.2
0.12	172.9	129.9	99.2	76.2	58.3	44.0	32.2	22.5	14.2	7.1	1.0	4.4	9.2	13.4	17.2	20.5
0.13	171.5	128.5	97.8	74.8	56.9	42.6	30.8	21.1	12.8	5.7	0.4	5.8	10.6	14.8	18.6	21.9
0.14	170.1	127.1	96.4	73.4	55.5	41.1	29.4	19.6	11.4	4.3	1.9	7.3	12.0	16.2	20.0	23.4
0.15	168.6	125.6	94.9	71.9	54.0	39.7	27.9	18.2	9.9	2.8	3.3	8.7	13.5	17.7	21.5	24.8
0.16	167.1	124.1	93.4	70.4	52.5	38.2	26.4	16.7	8.4	1.3	4.8	10.2	15.0	19.2	23.0	26.3
0.17	165.6	122.6	91.9	68.9	50.9	36.6	24.9	15.1	6.8	0.2	6.4	11.8	16.5	20.7	24.5	27.9
0.18	164.0	121.0	90.3	67.3	49.4	35.0	23.3	13.5	5.3	1.8	8.0	13.3	18.1	22.3	26.1	29.5
0.19	162.4	119.4	88.7	65.7	47.8	33.4	21.7	11.9	3.7	3.4	9.6	14.9	19.7	23.9	27.7	31.1
0.20	160.8	117.8	87.1	64.0	46.1	31.8	20.0	10.3	2.0	5.1	11.2	16.6	21.3	25.6	29.3	32.7
0.21	159.1	116.1	85.4	62.3	44.4	30.1	18.3	8.6	0.3	6.8	12.9	18.3	23.0	27.3	31.0	34.4
0.22	157.3	114.3	83.6	60.6	42.7	28.3	16.6	6.8	1.4	8.5	14.7	20.0	24.8	29.0	32.8	36.2
0.23	155.5	112.5	81.8	58.8	40.9	26.6	14.8	5.1	3.2	10.3	16.4	21.8	26.6	30.8	34.6	37.9
0.24	153.7	110.7	80.0	57.0	39.1	24.7	13.0	3.2	5.0	12.1	18.3	23.7	28.4	32.6	36.4	39.8
0.25	151.8	108.8	78.1	55.1	37.2	22.8	11.1	1.3	6.9	14.0	20.2	25.5	30.3	34.5	38.3	41.7
0.26	149.9	106.9	76.2	53.2	35.2	20.9	9.2	0.6	8.9	15.9	22.1	27.5	32.2	36.4	40.2	43.6
0.27	147.9	104.9	74.2	51.2	33.3	18.9	7.2	2.6	10.8	17.9	24.1	29.5	34.2	38.4	42.2	45.6
0.28	145.9	102.9	72.2	49.1	31.2	16.9	5.2	4.6	12.9	20.0	26.1	31.5	36.2	40.4	44.2	47.6
0.29	143.8	100.8	70.1	47.0	29.1	14.8	3.1	6.7	15.0	22.1	28.2	33.6	38.3	42.5	46.3	49.7
0.30	141.6	98.6	67.9	44.9	27.0	12.6	0.9	8.9	17.1	24.2	30.4	35.7	40.5	44.7	48.5	51.9
0.31	139.4	96.4	65.7	42.7	24.7	10.4	1.3	11.1	19.4	26.4	32.6	38.0	42.7	46.9	50.7	54.1
0.32	137.1	94.1	63.4	40.4	22.5	8.1	3.6	13.4	21.6	28.7	34.9	40.2	45.0	49.2	53.0	56.4
0.33	134.8	91.8	61.1	38.0	20.1	5.8	6.0	15.7	24.0	31.1	37.2	42.6	47.3	51.6	55.3	58.7
0.34	132.3	89.3	58.6	35.6	17.7	3.3	8.4	18.1	26.4	33.5	39.6	45.0	49.8	54.0	57.8	61.1
0.35	129.8	86.8	56.1	33.1	15.2	0.9	10.9	20.6	28.9	36.0	42.1	47.5	52.3	56.5	60.3	63.6
0.36	127.3	84.3	53.6	30.5	12.6	1.7	13.5	23.2	31.5	38.6	44.7	50.1	54.8	59.1	62.8	66.2
0.37	124.6	81.6	50.9	27.9	9.9	4.4	16.1	25.9	34.2	41.2	47.4	52.8	57.5	61.7	65.5	68.9
0.38	121.9	78.9	48.2	25.1	7.2	7.1	18.9	28.6	36.9	44.0	50.1	55.5	60.2	64.5	68.2	71.6
0.39	119.0	76.0	45.3	22.3	4.4	10.0	21.7	31.5	39.7	46.8	53.0	58.3	63.1	67.3	71.1	74.5
0.40	116.1	73.1	42.4	19.4	1.4	12.9	24.6	34.4	42.7	49.7	55.9	61.3	66.0	70.2	74.0	77.4
0.41	113.1	70.1	39.4	16.3	1.6	15.9	27.6	37.4	45.7	52.8	58.9	64.3	69.0	73.2	77.0	80.4
0.42	109.9	66.9	36.2	13.2	4.7	19.1	30.8	40.6	48.8	55.9	62.0	67.4	72.2	76.4	80.2	83.5
0.43	106.7	63.7	33.0	10.0	8.0	22.3	34.0	43.8	52.1	59.1	65.3	70.7	75.4	79.6	83.4	86.8
0.44	103.3	60.3	29.6	6.6	11.3	25.7	37.4	47.2	55.4	62.5	68.6	74.0	78.8	83.0	86.8	90.1
0.45	99.9	56.9	26.2	3.1	14.8	29.1	40.9	50.6	58.9	66.0	72.1	77.5	82.2	86.5	90.2	93.6
0.46	96.3	53.3	22.5	0.5	18.4	32.7	44.5	54.2	62.5	69.6	75.7	81.1	85.9	90.1	93.8	97.2
0.47	92.5	49.5	18.8	4.2	22.2	36.5	48.2	58.0	66.3	73.3	79.5	84.9	89.6	93.8	97.6	101.0
0.48	88.6	45.6	14.9	8.1	26.0	40.4	52.1	61.9	70.1	77.2	83.4	88.7	93.5	97.7	101.5	104.9
0.49	84.6	41.6	10.9	12.2	30.1	44.4	56.1	65.9	74.2	81.3	87.4	92.8	97.5	101.7	105.5	108.9
0.50	80.4	37.4	6.7	16.4	34.3	48.6	60.3	70.1	78.4	85.5	91.6	97.0	101.7	106.0	109.7	113.1

LSM release rate (combined intentional & unintentional)	Proportional exaggeration rate (i.e., 1/R -1)				
	1.1	**1.2**	**1.3**	**1.4**	**1.5**
0.00	9.0	11.8	14.3	16.7	18.8
0.01	10.1	12.9	15.4	17.8	19.9
0.02	11.2	14.0	16.5	18.9	21.0
0.03	12.3	15.1	17.7	20.0	22.1
0.04	13.5	16.3	18.8	21.1	23.3
0.05	14.6	17.4	20.0	22.3	24.5
0.06	15.8	18.6	21.2	23.5	25.7
0.07	17.1	19.9	22.4	24.7	26.9
0.08	18.3	21.1	23.7	26.0	28.1
0.09	19.6	22.4	24.9	27.3	29.4
0.10	20.9	23.7	26.3	28.6	30.7
0.11	22.2	25.0	27.6	29.9	32.1
0.12	23.6	26.4	29.0	31.3	33.4
0.13	25.0	27.8	30.4	32.7	34.8
0.14	26.5	29.2	31.8	34.1	36.3
0.15	27.9	30.7	33.3	35.6	37.7
0.16	29.4	32.2	34.8	37.1	39.2
0.17	31.0	33.7	36.3	38.6	40.8
0.18	32.5	35.3	37.9	40.2	42.4
0.19	34.1	36.9	39.5	41.8	44.0
0.20	35.8	38.6	41.1	43.5	45.6
0.21	37.5	40.3	42.8	45.2	47.3
0.22	39.2	42.0	44.6	46.9	49.1
0.23	41.0	43.8	46.4	48.7	50.8
0.24	42.8	45.6	48.2	50.5	52.7
0.25	44.7	47.5	50.1	52.4	54.6
0.26	46.7	49.5	52.0	54.3	56.5
0.27	48.6	51.4	54.0	56.3	58.5
0.28	50.7	53.5	56.0	58.4	60.5
0.29	52.8	55.6	58.1	60.5	62.6
0.30	54.9	57.7	60.3	62.6	64.8
0.31	57.2	60.0	62.5	64.8	67.0
0.32	59.4	62.2	64.8	67.1	69.3
0.33	61.8	64.6	67.1	69.5	71.6
0.34	64.2	67.0	69.6	71.9	74.0
0.35	66.7	69.5	72.1	74.4	76.5
0.36	69.3	72.1	74.6	77.0	79.1
0.37	72.0	74.7	77.3	79.6	81.8
0.38	74.7	77.5	80.0	82.4	84.5
0.39	77.5	80.3	82.9	85.2	87.4
0.40	80.5	83.3	85.8	88.1	90.3
0.41	83.5	86.3	88.8	91.2	93.3
0.42	86.6	89.4	92.0	94.3	96.4
0.43	89.9	92.7	95.2	97.5	99.7
0.44	93.2	96.0	98.6	100.9	103.0
0.45	96.7	99.5	102.0	104.4	106.5
0.46	100.3	103.1	105.7	108.0	110.1
0.47	104.1	106.8	109.4	111.7	113.9
0.48	107.9	110.7	113.3	115.6	117.8
0.49	112.0	114.8	117.3	119.7	121.8
0.50	116.2	119.0	121.5	123.9	126.0

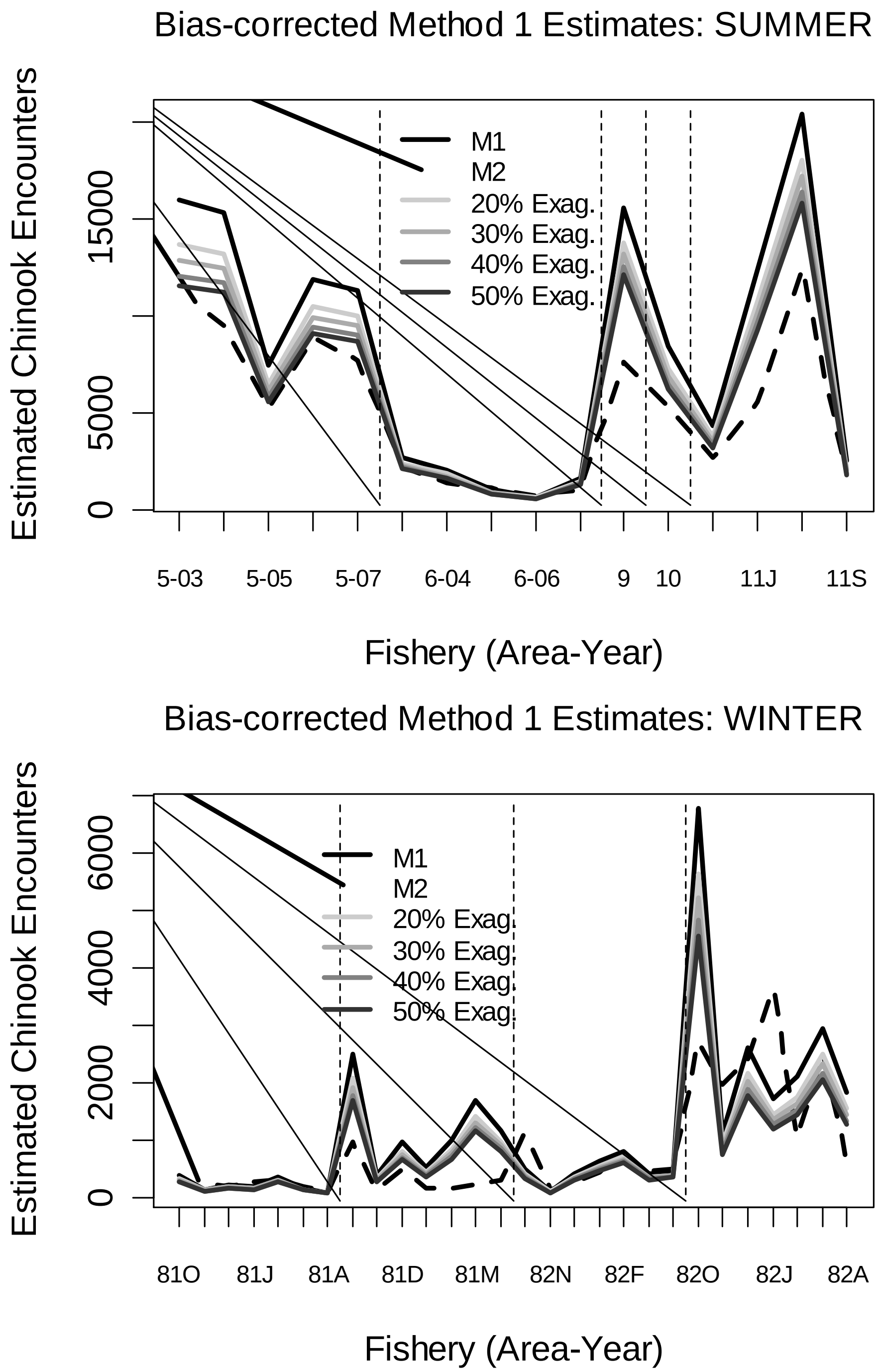

Figure E1. Effects of proportional reductions in M1 releases on total M1 encounters, by area, year, and/or period. With the exception of Areas 9, 10, and 11 (2007 all), *x*-axis ticks are labeled according to an Area-Year convention (e.g., "5-03" is Area 5 in 2003) and are ordered sequentially from left to right for summer fisheries (*upper panel*). For winter fisheries (*lower panel*) and Area 11 (summer 2007), *x*-axis ticks follow an Area-Month convention (e.g., "81O" is 8-1 October) and are sequentially ordered left to right. Vertical dashed lines delimit breaks between major groupings (Area for fisheries having either one or an annual series of season-total estimates [5, 6, 9, 10]; and Area-year/season [e.g., 2005-6] for areas with multiple monthly estimates in a single season [8-1, 8-2, and 11]).

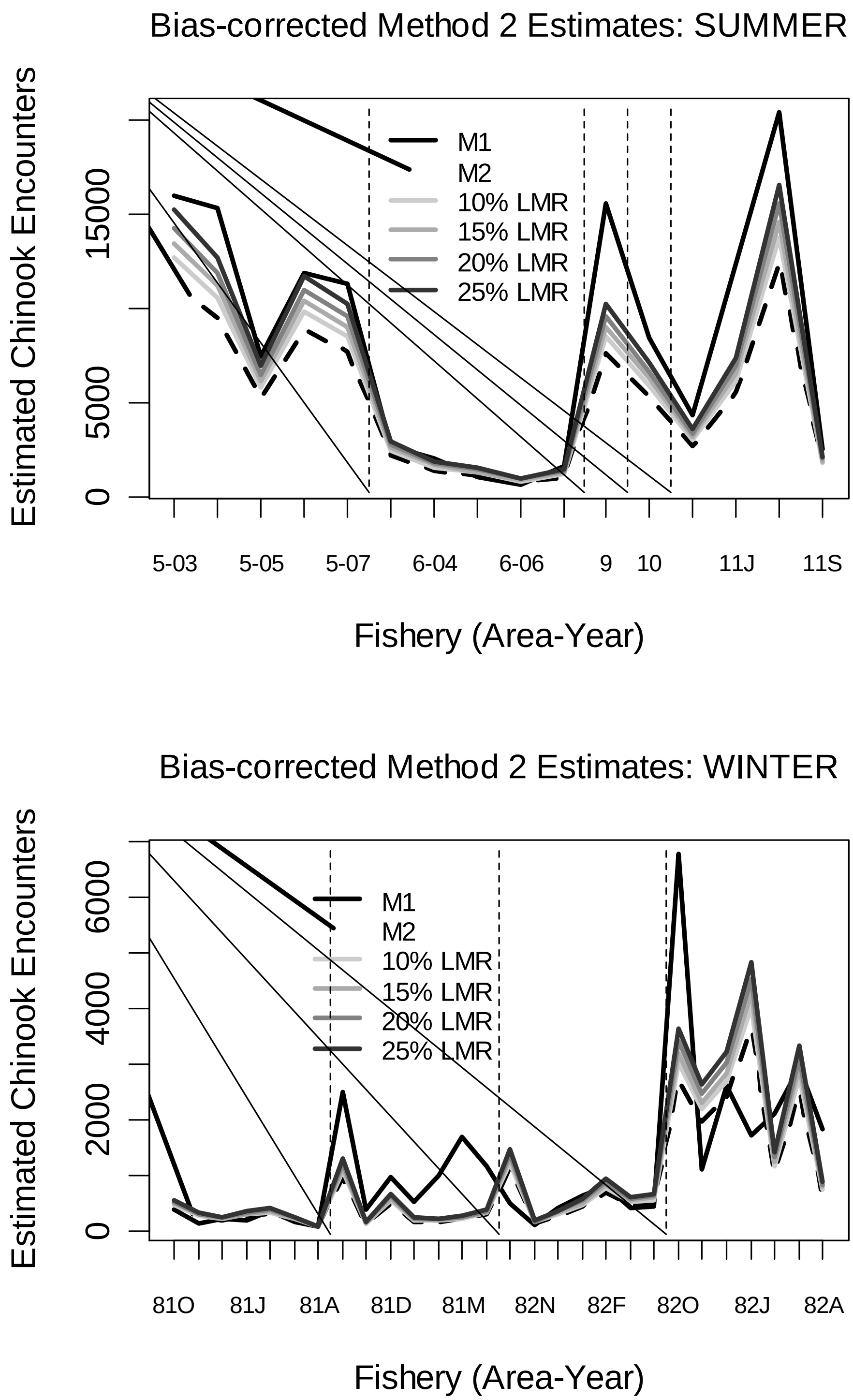

Figure E2. Effects of varying LSM Chinook release rates ("LMR" in legend) on M2 encounters, by area, year, and/or period. All other notation follows that described in the Figure E1 caption.