Bias in the Estimation of Impacts of Simultaneous Mark-Selective and Non-selective Fisheries on Ocean Salmon

Henry Yuen
U.S. Fish and Wildlife Service
1211 SE Cardinal Court, Suite 100
Vancouver, WA 98683

and

Robert Conrad
Northwest Indian Fisheries Commission
6730 Martin Way E.
Olympia, WA 98516

Abstract

In mark-selective salmon fisheries, current management models produce biased estimates of the mortalities in those fisheries and concurrent non-selective fisheries. When a non-selective fishery is prosecuted in the same time and area as a mark-selective fishery, the non-selective fishery harvests fewer marked fish and more unmarked fish than expected because of the increase in the unmarked-to-marked fish ratio caused by the selective fisheries in addition to the increased probability of an unmarked fish encountering the gear more than once due to the required release on all unmarked fish. This bias is an increasing function of the harvest rate on marked fish. The expected exploitation rates must also take into account mark-recognition errors where marked fish are released by mistake and unmarked fish are landed by mistake. This mark-recognition error adjustment is a function of unmarked-to-marked fish ratios. We illustrate these effects and describe their magnitude.

Introduction

The coded-wire tag (CWT) sampling program on the west coast of the United States and Canada allows fishery managers to estimate the exploitation rates on hatchery salmon stocks (Johnson 1980). This information is then used to estimate the exploitation rates of wild untagged salmon stocks with similar ocean and fishery distributions. Hatchery fish tagged with a CWT are also marked with an adipose fin clip to facilitate their identification by fishers and catch samplers. There are few tagging programs on wild stocks and therefore most fish with an adipose fin clip are hatchery origin.

As early as 1991, numerous wild salmon species and stocks in Puget Sound, the Columbia River, and in California were being listed for protection under the Endangered Species Act (ESA), starting with Snake River sockeye salmon. In 1998, declines in the Skeena and Thompson River coho population led to mandatory non-retention of wild coho in British Columbia fisheries (Irvine and Bradford 2008). Where ever wild and hatchery fish are harvested together, any limitation on wild harvest rates was essentially a limitation on the entire fishery. In order to provide meaningful fisheries on abundant hatchery fish, the Washington State Legislature directed its state hatcheries to begin mass marking, using adipose fin clips, coho (*Oncorhynchus kisutch*) in 1997 and Chinook (*O. tshawytscha*) in 1998 (Ashbrook 2008). Congress also directed the US Fish and Wildlife Service to implement a system of mass marking starting in 2003 for all salmon intended for harvest and released from Federally operated or funded hatcheries in Washington and Oregon. Wild fish and any hatchery fish intended for conservation are not marked allowing fishery managers to prosecute a mark-selective fishery (MSF) where marked hatchery fish are landed and unmarked natural origin or hatchery fish that are produced for stock rebuilding purposes are released. In 1998, Canada initiated its mark-selective salmon fisheries program for coho.

Harvest limits for coho and Chinook salmon are set by the Pacific Fishery Management Council (PFMC) in Federal waters off the coasts of California, Oregon, and Washington (PFMC 1999) and by the Pacific Salmon Commission (PSC) for ocean fisheries in southeast Alaska and Canada. All management agencies (state, Tribal, and Canada Department of Fisheries and Oceans) require the accounting of all sources of mortality including landed mortality (catch), incidental (non-landed) mortalities due to a fish being handled and released, and drop-off mortality (from the gear prior to landing), and mortality due to mark-recognition error (releasing a marked fish when it should have been retained) and mark-retention error (landing an unmarked fish when it should have been released).

Salmon management models are used annually by fisheries management agencies for pre-season prediction of impacts for a proposed suite of fishery regulations and for post-season assessment of completed fisheries. The Fishery Regulation Assessment Model (FRAM) currently used by the PFMC and co-managers for salmon fisheries in Washington marine waters is an example (PFMC 2008). Currently, these models are single-pool, deterministic models that operate on discrete time steps whose length varies from one month (e.g., coho during the summer months) to several months (e.g., Chinook). All fisheries during a time step are assumed to operate on a single pool of fish simultaneously. The pool of fish consists of all stocks that have been caught historically in the fishery as estimated from coded-wire tag recoveries (Nandor et al. 2010). Historical exploitation rates estimated from CWTs recovered during a base period when salmon abundances were relatively high and fisheries were widely distributed in both time and area are the basis for the predictions by these models (Pacific Salmon Commission 2005).

An assumption common to all these models prior to the implementation of mark-selective fisheries was that the exploitation rate for specific marked salmon stocks (called indicator stocks) was representative of the exploitation rate for unmarked stocks with similar life-histories and ocean distributions. With the advent of mark-selective fisheries, the models were restructured so that the exploitation rates for marked stocks were used to represent the encounter rate in mark-selective fisheries for the unmarked stocks that they represent (PFMC

2008). These encounter rates are used to produce stock-specific estimates of the number of encounters of unmarked fish to which an estimate of the release- mortality rate was applied to estimate mortalities due to the catch and release of unmarked salmon in mark-selective fisheries. In these simple models, unmarked mortality (m_U) is a function of the encounter (λ_U) and release-mortality rates (δ). The encounter rate in turn is linearly related to the exploitation rate on the marked indicator stock used to represent the unmarked stock (ER_M). The exploitation rate on the unmarked fish (ER_U) is the sum of the unmarked mortalities (see Table 1 for a list of the parameters and their values), i.e.

$$\lambda_U = ER_M. \tag{1}$$

$$m_U = \lambda_U \mathrm{X}\, \delta \tag{2}$$

$$ER_U = \frac{\sum_{f=1}^{F} m_{U,f}}{U} \tag{3}$$

where F = total number of fisheries (e.g., 3).

Table 1. Parameters and variables used in the selective-fishery model.

Parameter	Definition and value(s)
A	Adjustment for marked fish released by mistake and unmarked fish landed by mistake: 0.990099 for 3:1 unmarked-to-marked starting cohort ratios, 1.030928 for 1:1, and 1.045296 for 1:3. γ = 0.95 and ζ = 0.98 in all unmarked-to-marked ratios.
b	Multiple-encounter parameter that determines the increase in the release-mortality rate with successive releases. Set to 1.0 (i.e., no increase) or 0.843 (representing a 25% increase)
α	Drop-off mortality per handle rate (i.e., landed + released fish) rate: the probability that a hooked fish escapes and dies before being brought to the boat. Set to 0.0 (none) or 0.05.
ER	Target exploitation rate for all three simultaneous fisheries combined where landings include marked and unmarked fish (either targeted or by accident). Range from 0.1 to 0.4 in 0.1 increments.
M	Initial number of marked fish. Range from 100,000 to 300,000.
$m_{i,f}$	Number of unmarked (i = U) or marked (i = M) mortalities in

	fishery f.
R	Starting ratio of unmarked fish to marked fish. Set to 1:3, 1:1, and 3:1.
RMR	Effective release-mortality rate that can account for an increase in the release-mortality rate δ when a fish is released more than once.
U	Initial number of unmarked fish. Range from 100,000 to 300,000.
γ	Mark-recognition rate: the probability that a marked fish that is brought to the boat is properly identified as a marked fish and retained. Set to 1.0 (for all non-selective fisheries or when assuming perfect recognition rate) or 0.95.
δ	Release-mortality rate: probability that a fish dies after its first release. Values of 0.14 and 0.26 were used for the two mark-selective fisheries modeled.
ζ	Recognition rate for unmarked fish: the probability that an unmarked fish brought to the boat is recognized as unmarked and released in a MSF. Set to 1.0 (for all NSF fisheries or when assuming perfect recognition rate) or 0.98.
λ	Expected encounter rate of a fish with the gear.
π_f	Proportion of total landings for the marked cohort in all fisheries that occurred during fishery f. Set to total MSF-to-NSF target exploitation rate ratios of 1:2, 1:1, and 2:1. Of the two MSF, the target exploitation rate of the MSF with $\delta = 0.14$ was arbitrarily double that of the one with $\delta = 0.26$.

Lawson and Sampson (1996) demonstrated that in a mark-selective fishery, the mortality rate of unmarked fish is an increasing function of the apparent harvest rate and the release-mortality rate. This results in the total number of unmarked mortalities in mark-selective fisheries being underestimated in models relying on the linear relationship between exploitation rate and release-mortality rate. Any combination of simultaneous mark-selective and non-selective fisheries (NSF) greatly increases the complexity of estimating mortalities for both unmarked and marked stocks. For example, a mark-selective troll fishery and a mark-selective recreational fishery each with different release-mortality rates, operating in the same area and during the same time step as a non-selective troll fishery. The dynamic interactions between the competing fisheries are best explored with an individual-based simulation model that monitors the fate of each fish vulnerable to the fisheries.

Methods

Our simulation model builds upon the individual-based model in Lawson and Sampson (1996) with the following modifications:

- We used a power function to calculate the increase in effective release-mortality rate with each successive encounter.

$$\boldsymbol{RMR} = \delta^{b^{\textbf{number of times released}}} \tag{4}$$

where *b* = multiple-encounter mortality parameter (Figure 1). For the simulations we used values of 1.0 or 0.843 for *b,* which are the equivalent of no increase and about a 25% increase (Δ = 0.25 in Figure 4 of Lawson and Sampson 1996) in effective release-mortality rate with successive releases.

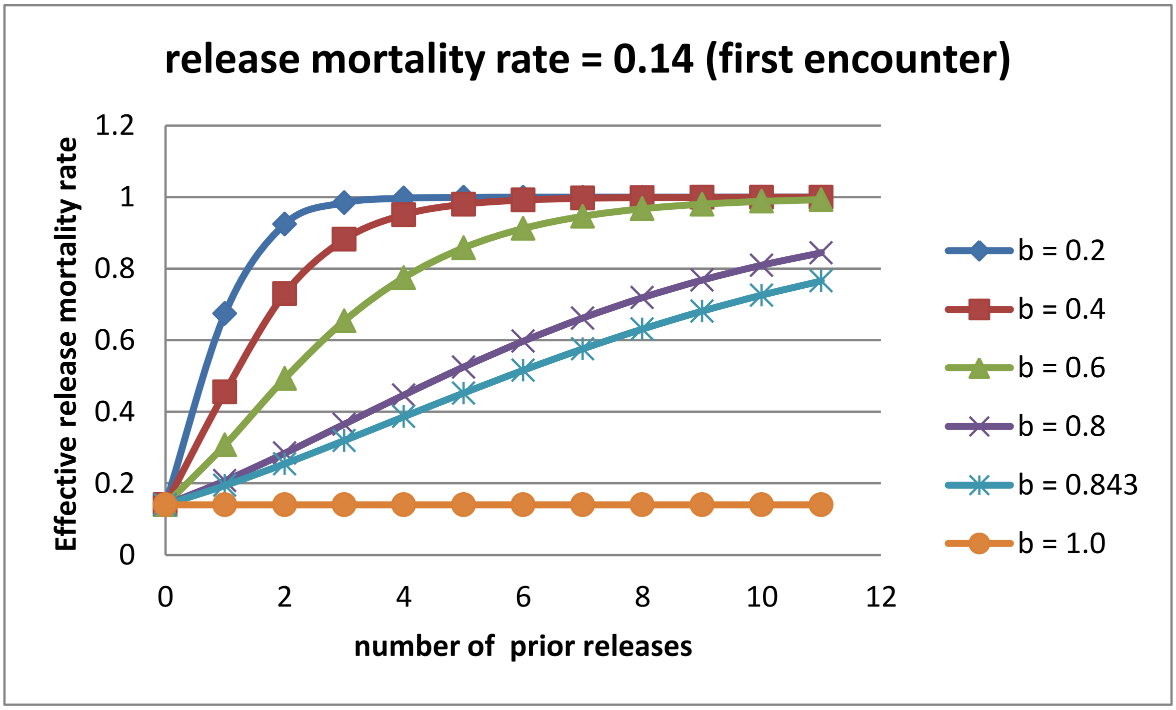


Figure 1. Increasing effective release-mortality rate as a power function of successive releases (relationship for the initial Washington ocean sport release-mortality rate of 0.14).

- There were three fisheries operating simultaneously in our model: MSF 1 (e.g., sport) with δ = 0.14, and MSF 2 (e.g., non-Indian troll) with δ = 0.26, and NSF (e.g., Treaty Indian troll).

- In both Lawson and Sampson (1996) and our models, there is either a catch quota or a target harvest rate. Each fishery in our model will achieve its own unique catch quota (i.e., assume perfect management), as opposed to a common catch quota for the pool of fisheries. The corresponding target exploitation rate in each fishery, based either on the marked fish only in a mark-selective fishery or on both marked and unmarked fish in a non-selective fishery, can be calculated from the catch quota and the corresponding starting cohort size. Neither our model nor Lawson and Sampson (1996) were designed to model a fishery based on length of season or fishing effort.

- In both Lawson and Sampson (1996) and our models, there is a fish population with *U* unmarked and *M* marked fish available to all fisheries operating during the modeled time period (and area). While the model is running, individual fish are selected at random and the ensuing chain of events depends on the following (see Table 2 for pseudo code). Is this fish alive? If not, select another fish at random. If yes, then (in our model) select a fishery at random according to the distribution of catch quotas among the fisheries.
    - Is this fish a “drop-off” mortality with a probability of α (See Table 1 for list of parameters and their values)? If yes, tally as a mortality and select another fish.
    - If a NSF, tally as a mortality and select another fish.
    - If a MSF, look up the number of prior encounters for this fish and increase the effective release-mortality rate according to Equation 4. Does the fisher correctly recognize it as a marked or unmarked fish with a probability of γ and ζ, respectively? If the fish was released either because the fisher recognized an unmarked fish or did not correctly recognize a marked fish, did the fish survive gear-related injuries with a probability of (1- *RMR*)? If the fish survived all of the above it was returned to the population, otherwise it was tallied as a mortality. Repeat the process until the target exploitation rate or catch quota for each fishery is achieved. A complete capture history was maintained for each fish in the population that recorded each encounter, the fishery it occurred in, and the fate of that encounter: drop-off mortality, landed catch, release and survival, or release mortality.

Table 2. Pseudo code for chain of events in mark-selective fisheries and consequences.

```
1. Assign each fish in the population with a unique identification number and set its flag as either marked or unmarked according to the marked proportion.
2. Specify the release-mortality rate, e.g., 0.14 for ocean sport fisheries.
3. Specify the target marked harvest rates, e.g. 0.1, 0.2, 0.3, or 0.4.
4. Initialize the number of encounters for each fish to zero.
5. Select a fish at random from combined pool of marked and unmarked fish (i.e., draw first random number – this simulates being caught by the gear).
6. If fish is alive then
    a. Select a fishery at random.
    b. Increase number of encounters (fish) + 1.
    c. Draw second random number from probability between 0 and 1.  If second random number < drop-off/encounter rate then (note: 0.047619 drop-off/encounter = 0.05 drop-off/handle).
        i. Drop-off mortality.
        ii. Go to step 5.
    d. Else not a drop-off and fish is unmarked then
        i. Draw third random number from probability between 0 and 1. If  probability < unmarked recognition rate (0.98) then
            a. Unmarked fish is correctly identified and released.
            b. Use Equation 4 to calculate effective release-mortality rate.
            c. Draw fourth random number from probability between 0 and 1. If fourth random number < effective release-mortality rate then unmarked release mortality.
            d. Go to step 5
        ii. Else unmarked fish incorrectly identified as marked
            a. Unmarked fish landed by mistake.
            b. If accumulated landed fish = target marked harvest rate, then stop fishery.
            c. If accumulated landed fish < target marked harvest rate  then go to step 5.
    e. Else not a drop-off and fish is marked then
        i. Draw third random number from probability between 0 and 1. If probability < mark-recognition rate (0.94) then
            a. Marked fish correctly identified and landed.
            b. If accumulated landed fish = target marked harvest rate, then stop fishery.
            c. If accumulated landed fish < target marked harvest rate then go to step 5.
        ii. Else  marked fish incorrectly identified as unmarked
            a. Marked fish released by mistake.
            b. Use Equation 4 to calculate effective release-mortality rate.
            c. Draw fourth random number from probability between 0 and 1.  If probability < effective release-mortality rate then marked fish release mortality.
            d. Go to step 5.
```

- Lawson and Sampson (1996) modeled drop-offs with two parameters, drop-off rate X drop-off mortality rate, which implies an opportunity for subsequent encounter if the fish survived the drop-off. We simply modeled the probability of being a drop-off mortality (α).

We examined total exploitation rates (across all three modeled fisheries) from 0.10 to 0.40 in increments of 0.10. For each MSF, the target exploitation rate is multiplied by the marked cohort size (M) to specify a marked-catch quota for the fishery. For the non-selective fishery, the catch quota is specified as the product of the target exploitation rate for the marked cohort and the sum of M and U. Because the marked cohort is used as an indicator stock for the unmarked cohort, any target exploitation rate specified for the marked cohort is also the target for the unmarked cohort. The simulations were run until the individual catch quotas in each fishery were met.

We simulated each of the three fisheries operating alone as a base model for comparison in addition to simulating all three operating concurrently on the same pool of fish (Table 3). Each simulation began with an initial population of 400,000 total fish. Simulations were run using three different unmarked-to-marked fish ratios, 1:1, 1:3, and 3:1, to divide the initial pool into unmarked and marked fish cohorts. There were also three different total MSF-to-NSF harvest rate ratios, 1:2, 1:1, and 2:1. In one of the MSF, $\delta = 0.14$ (e.g., sport fishery) and in the other $\delta = 0.26$ (e.g., troll fishery). In all of the simulations, the target exploitation rate of the MSF with $\delta = 0.14$ was arbitrarily double that of the one with $\delta = 0.26$.

We ran simulations with four levels of increasing complexity (Table 3).

- Drop-off mortality rate = 0, mark and unmarked recognition rate = 1.0. The expected mortalities, m_f, in fishery f was calculated from the total expected encounters, e.g., $M \times ER$, and the proportion of the total mortalities in all fisheries that occurred in fishery f, (π_f). In a non-selective fishery, $RMR = 1$.

$$m_{M,f} = M \times ER_M \times \pi_f \tag{5}$$
$$m_{U,f} = U \times ER_M \times \pi_f \times RMR \tag{6}$$

- Drop-off mortality rate, d, = 0.05, mark and unmarked recognition rate = 1.0. The expected mortalities were adjusted for drop-off per handle, d_f, as follows where $\gamma = \zeta = 1$.

$$m_{M,f} = M \times ER_M \times \pi_f \times (\gamma + d_f) \tag{7}$$
$$m_{U,f} = U \times ER_M \times \pi_f \times (\zeta \times RMR + d_f) \tag{8}$$

- Drop-off mortality rate = 0.05, 0.95 mark-recognition rate and 0.98 unmarked-recognition rate. Because catch quota is the sum of marked catch plus unmarked fish landed by mistake, the expected marked encounter rate had to be adjusted for unmarked landings and the expected unmarked encounter rate had to be adjusted for marked releases. The mark-recognition error adjustment, *A*, was a function of the U:M ratio, marked recognition rate, and unmarked recognition rate and was found by solving for the mark-recognition error adjustment that resulted in the marked and unmarked landings equal to the catch quota. The FRAM model, however, does not have the mark-recognition error adjustment *A*.

$$m_{M,f} = M \times ER_M \times A_{U:M,\gamma,\zeta} \times \pi_f \times (\gamma + d_f + (1-\gamma) \times RMR) \tag{9}$$

$$m_{U,f} = U \times ER_M \times A_{U:M,\gamma,\zeta} \times \pi_f \times (\zeta \times RMR + d_f + (1-\zeta)) \tag{10}$$

- Drop-off mortality rate = 0.05, 0.95 mark-recognition rate and 0.98 unmarked-recognition rate, and *b* = 0.843 which will produce a 25% increase in release-mortality rate with each subsequent encounter. RMR was calculated using Equation 4.

Table 3. Summary of simulated multiple-encounter scenarios. All scenarios were repeated with each fishery operating alone (base model) and all three fisheries operating in the same time step.

Simulation Model Summary	Release-mortality rates	Drop-off mortality per handle rate, mark-recognition rate, unmarked-recognition rate	Increase in release-mortality rate with each subsequent encounter
Release mortality only	δ = 0.14 and 0.26	α = 1.0, γ = 1.0, ζ = 1.0	*b* = 1.0
Add drop-off	δ = 0.14 and 0.26	α = 0.05, γ = 1.0, ζ = 1.0	*b* = 1.0
Add mark-recognition error	δ = 0.14 and 0.26	α = 0.05, γ = 0.95, ζ = 0.98	*b* = 1.0
Add increased release-mortality rate	δ = 0.14 and 0.26	α = 0.05, γ = 0.95, ζ = 0.98	*b* = 0.843

We calculated the mean relative bias from the difference in unmarked ER (Equation 3) from our simulations (model) and the expected values (Equations 5 through 10)

$$bias = \frac{\sum \frac{ER(model) - ER(expected)}{ER(expected)}}{n} \tag{11}$$

where *n* = number of simulations.

Results

We ran at least 25 simulations per scenario and up to 250 simulations when R = 3:1 (all levels of MSF:NSF ratios) and when R = 1:1 if the MSF:NSF ratio was less than 2:1. In those instances, especially at the lower target exploitation rates, the numbers of marked encounters were not large enough to produce stable results.

When a fishery operates alone and landings and release mortalities are the only sources of mortality, any biases in estimated exploitation rate are due to the accounting of multiple encounters (Figure 2). The scenario in the upper panel of Figure 2 represents a typical MSF observed in ocean coho salmon fisheries where the starting unmarked-to-marked cohort ratio is less than 1 and the combined MSF exploitation rate is less than that of the non-selective fisheries. When comparing the various scenarios, there should be a range from no bias (except for random noise) in the non-selective fishery to greater bias in the fisheries with the lower release-mortality rates (δ). Biases should increase with exploitation rate, an indicator of multiple encounter rates. Given a range of target total exploitation rates from 0.1 to 0.4 in the simulation behind Figure 2, the average number of fish with multiple encounters ranged from 144 to 2,424, respectively and the maximum number of encounters per fish ranged from 3 to 4, respectively. Neither the trend in the MSF-to-NSF exploitation rate ratios nor the trend in unmarked-to-marked ratios affects the relationship between bias and expected estimated exploitation rate.

Adding drop-off as a source of mortality to a fishery operating alone does not change the results shown in Figure 2. Adding mark and unmarked recognition error rates as a source of mortality to the same fishery reduces the biases in the MSF (Figure 3). When the unmarked-recognition error is greater than the mark-recognition error and the catch quota includes unmarked fish landed by mistake, the required number of marked encounters in a MSF declines as a result of unmarked fish landed by mistake. The number of unmarked encounters also declines because of its relationship to the marked encounter rate (Equation 10). Increasing the release-mortality rate with successive encounters produces greater biases in the MSF (Figure 4).

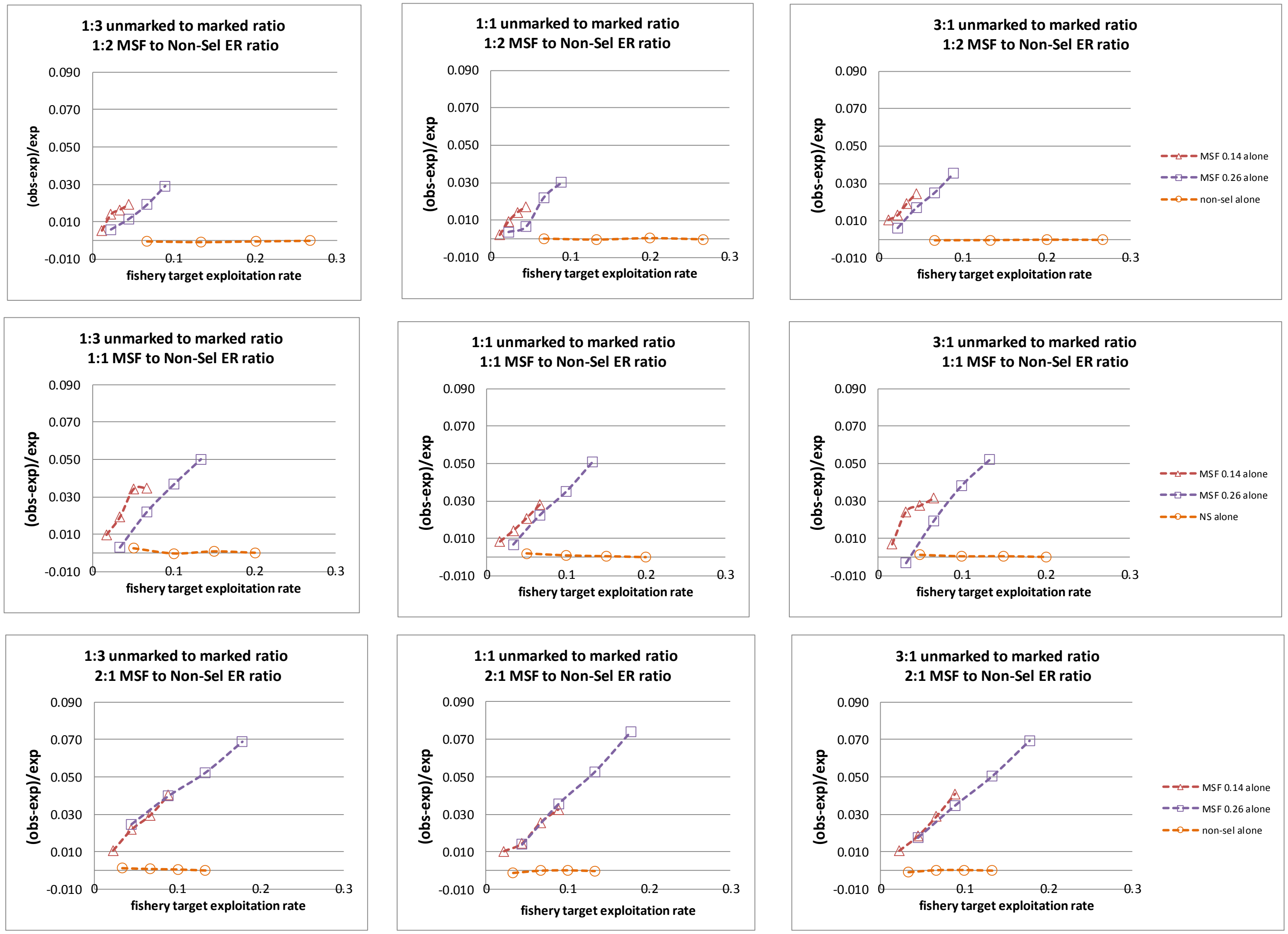


Figure 2. Bias in estimated unmarked exploitation rates in two MSF (δ = 0.14 and 0.26 respectively) and one non-selective fishery operating alone with landings and release mortality as the only sources of mortality. Note when the MSF-to-NSF exploitation rate ratios change, the target exploitation rates will also change.

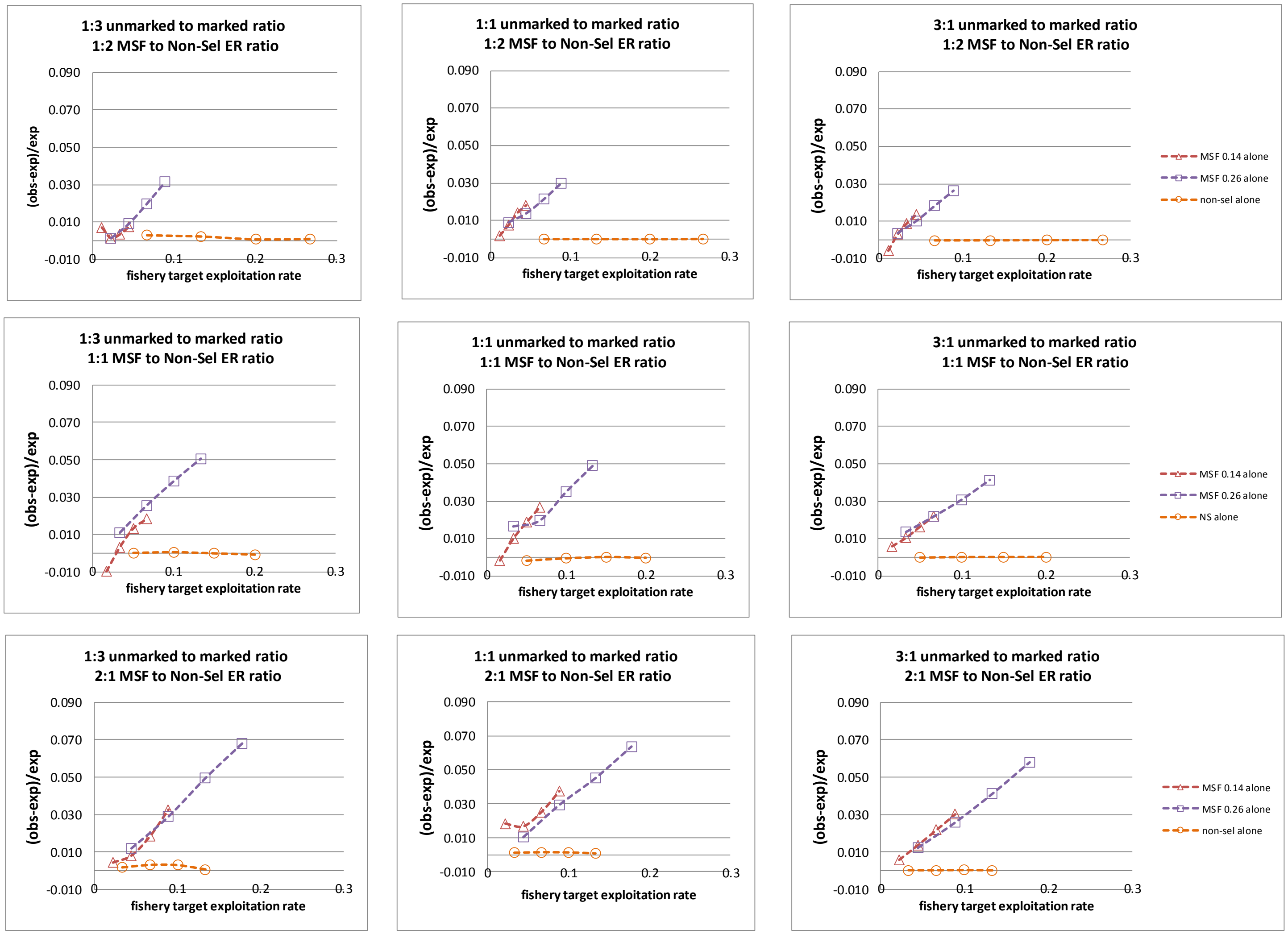


Figure 3. Bias in estimated unmarked exploitation rates in two MSF (δ = 0.14 and 0.26 respectively) and one non-selective fishery operating alone with landings, drop-offs, release mortality, plus mark and unmarked recognition errors as the sources of mortality. Note when the MSF-to-NSF exploitation rate ratios change, the target exploitation rates will also change.

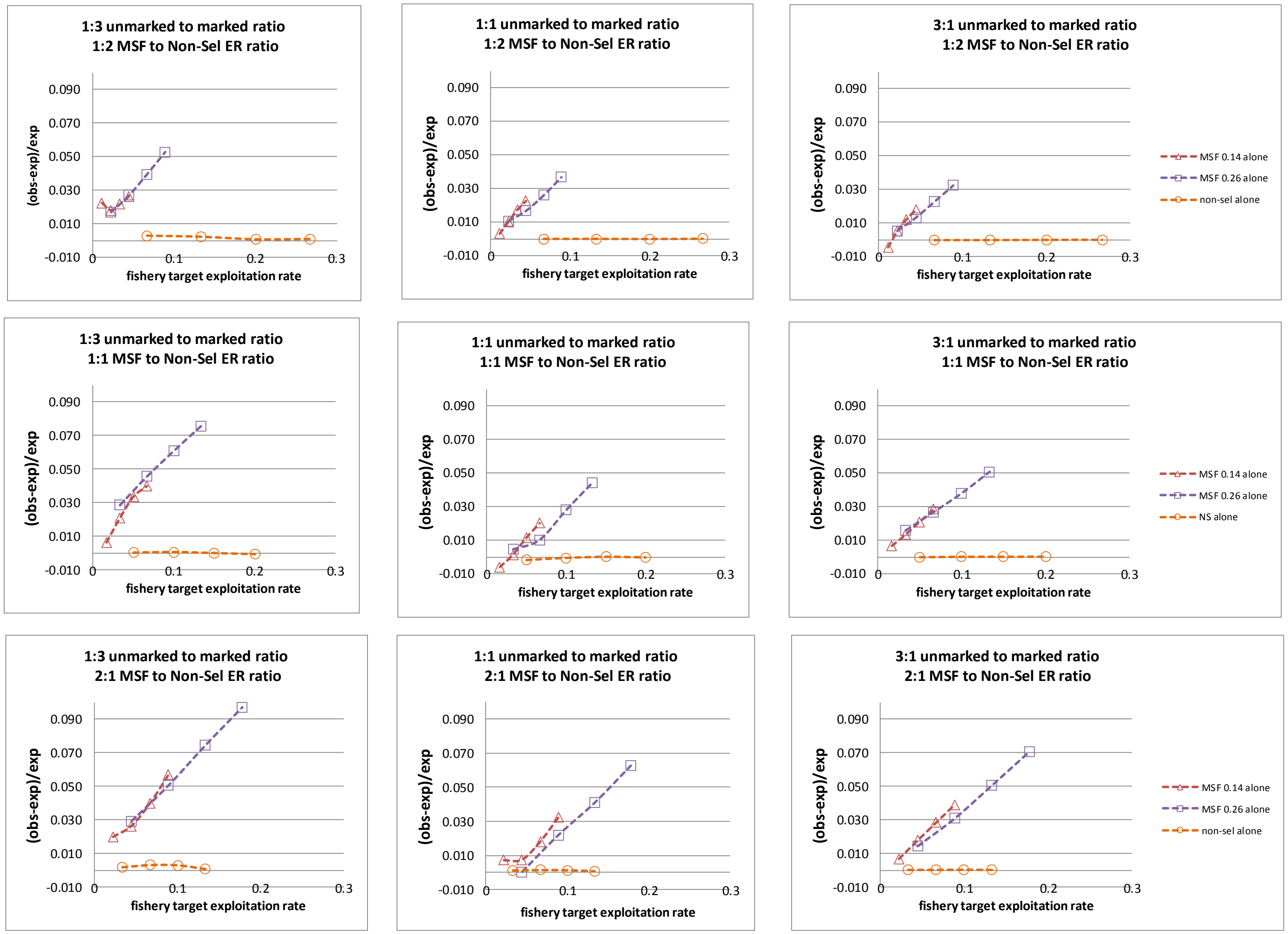


Figure 4. Bias in estimated unmarked exploitation rates in two MSF (δ = 0.14 and 0.26 respectively) and one non-selective fishery operating alone with landings, drop-offs, mark and unmarked recognition errors, and increasing release mortality with successive encounters as the sources of mortality. Note when the MSF-to-NSF exploitation rate ratios change, the target exploitation rates will also change.

With landings and release mortalities as the only source of mortality, operating MSF and NSF simultaneously in the same time period and area increases the unmarked-to-marked fish ratio from the removal of more marked than unmarked fish by the MSF. In the upper left panel of Figure 5 the starting unmarked cohort proportion was 0.333 and the ending proportions were 0.343, 0.353, 0.366, and 0.381 after the simultaneous fisheries achieved a combined target exploitation rate of 0.1, 0.2, 0.3, and 0.4, respectively. Not only did this increase the biases in the MSF, it also introduced a bias in the NSF where none existed when the non-selective fishery was prosecuted in isolation. This bias in the estimated exploitation rate for the unmarked cohort in the non-selective fishery can be as large as the analogous bias present in the mark-selective fisheries.

For reasons that we do not understand, adding drop-off mortality to simultaneous fisheries increased the biases in the MSF when the unmarked-to-marked fish ratio was 1 or less and decreased it when the ratio was greater than 1 (Figure 6). Adding mark and unmarked recognition errors to simultaneous fisheries had the effect of reducing the number of marked encounters required to achieve a catch quota because of unmarked fish landed by mistake and consequently reducing the biases among the MSF if the unmarked-to-marked fish ratio was less than or equal to 1 but not in the non-selective fishery regardless of the unmarked–to-marked fish ratio (Figure 7). There is no noticeable effect on the bias in the non-selective fisheries. Adding increased release-mortality rate with successive encounters to simultaneous fisheries produced a relatively small increase in the biases among the MSF (Figure 8).

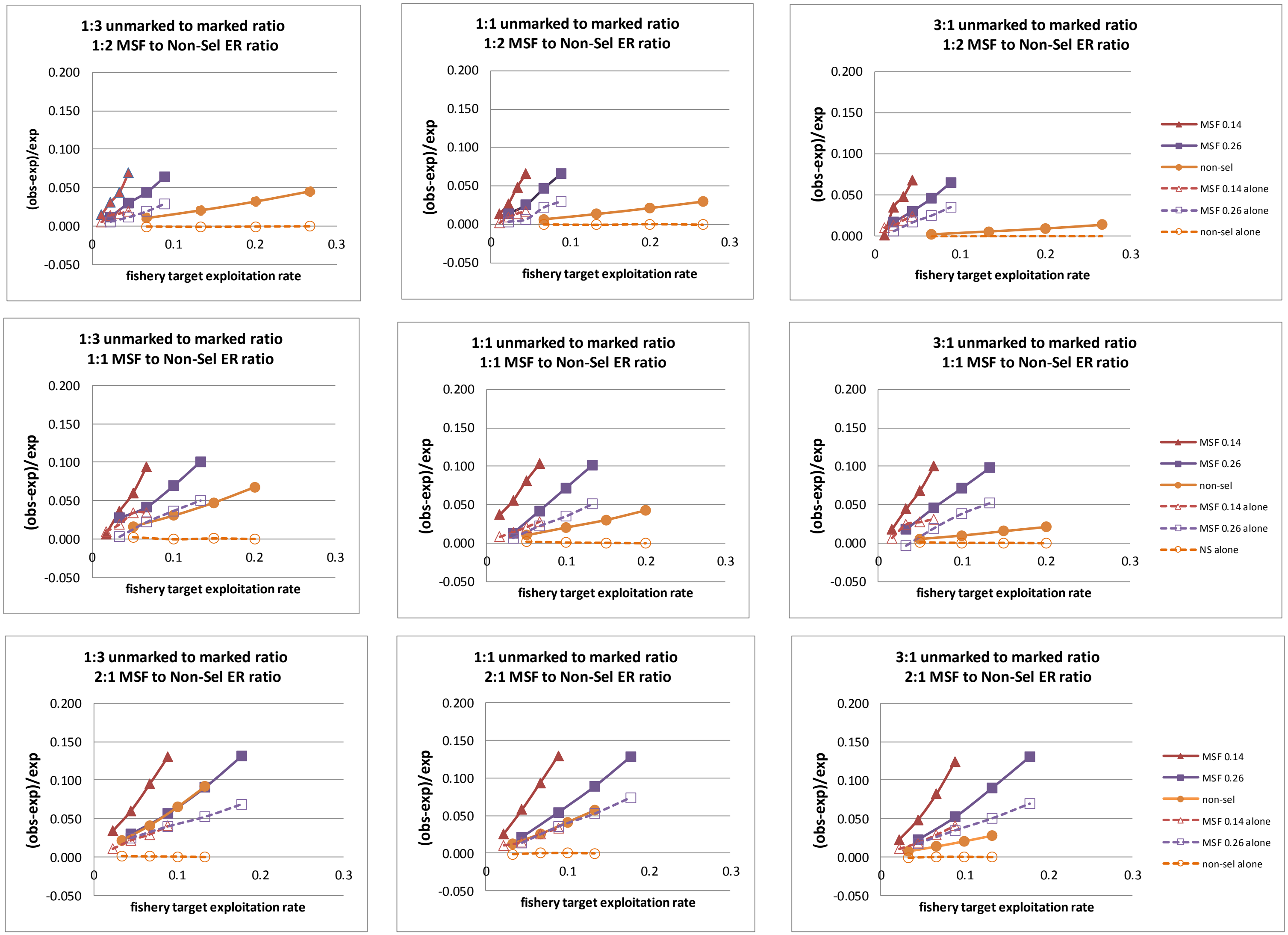


Figure 5. Bias in estimated unmarked exploitation rates in two MSF (δ = 0.14 and 0.26 respectively) and one non-selective fishery operating simultaneously and alone with landings and release mortality as the sources of mortality. Note when the MSF–to- NSF exploitation rate ratios change, the target exploitation rates will also change.

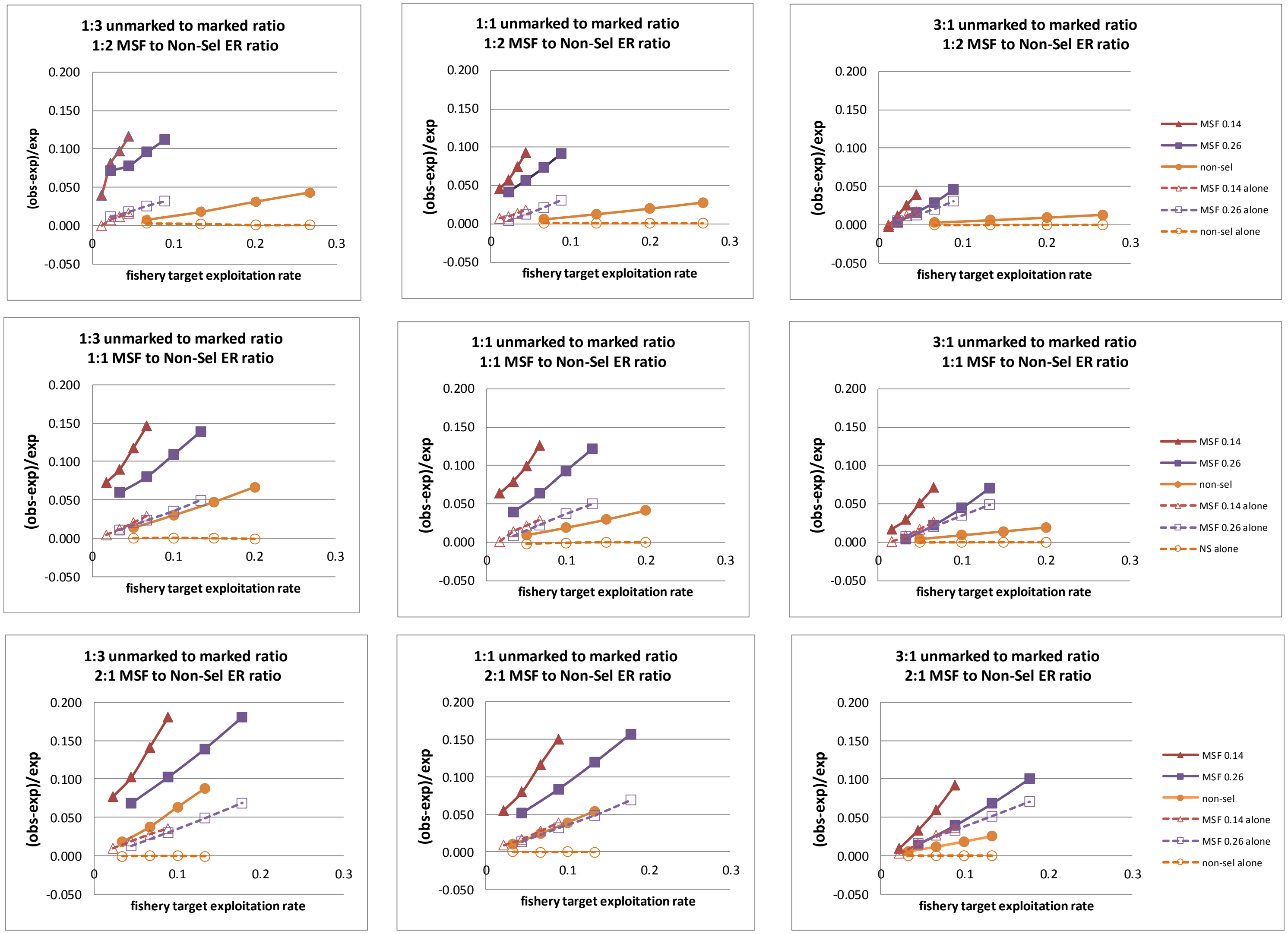


Figure 6. Bias in estimated unmarked exploitation rates in two MSF (*δ* = 0.14 and 0.26 respectively) and one non-selective fishery operating simultaneously and alone with landings, release mortality, and drop-off as the sources of mortality. Note when the MSF-to-NSF exploitation rate ratios change, the target exploitation rates will also change.

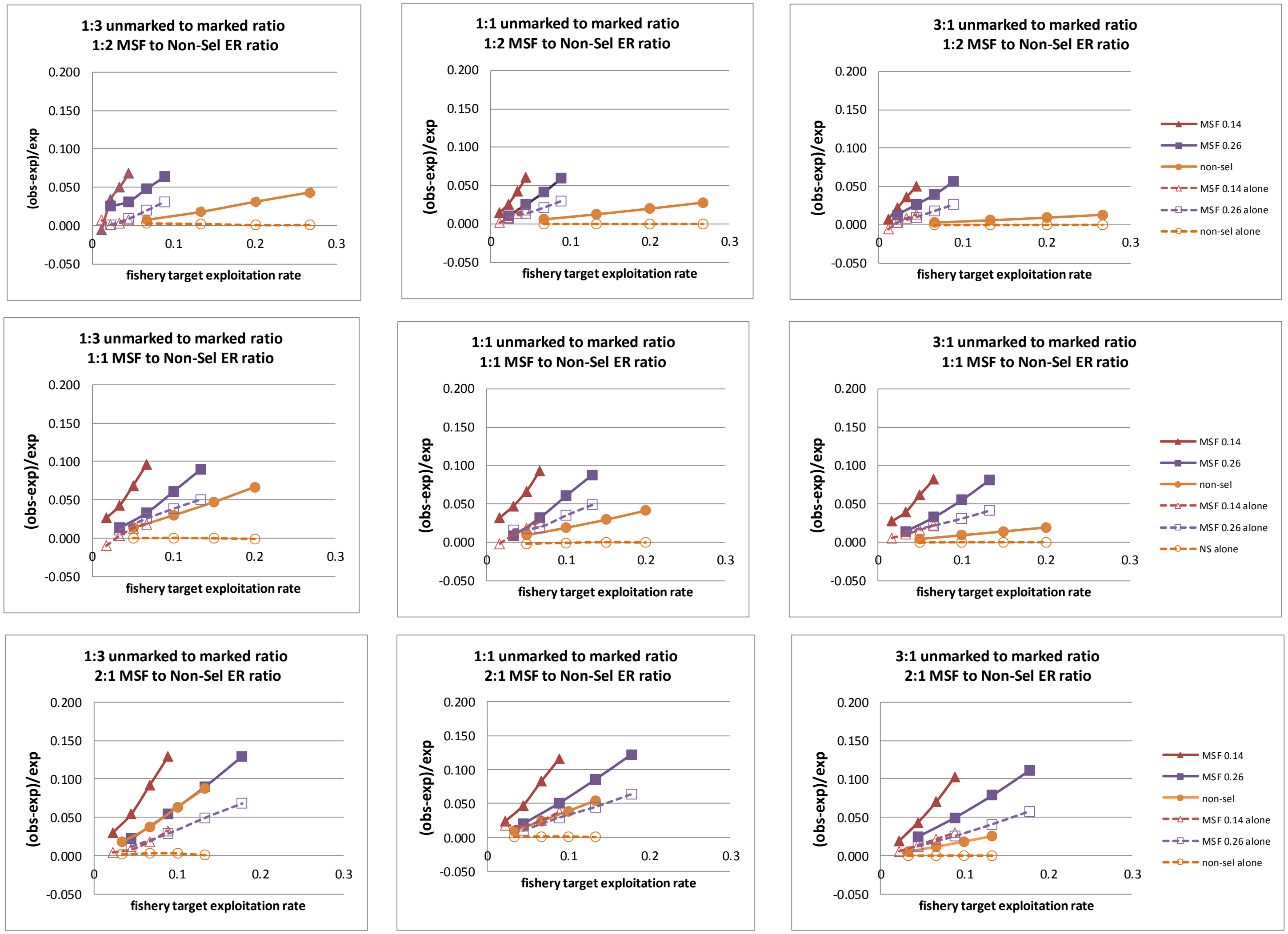
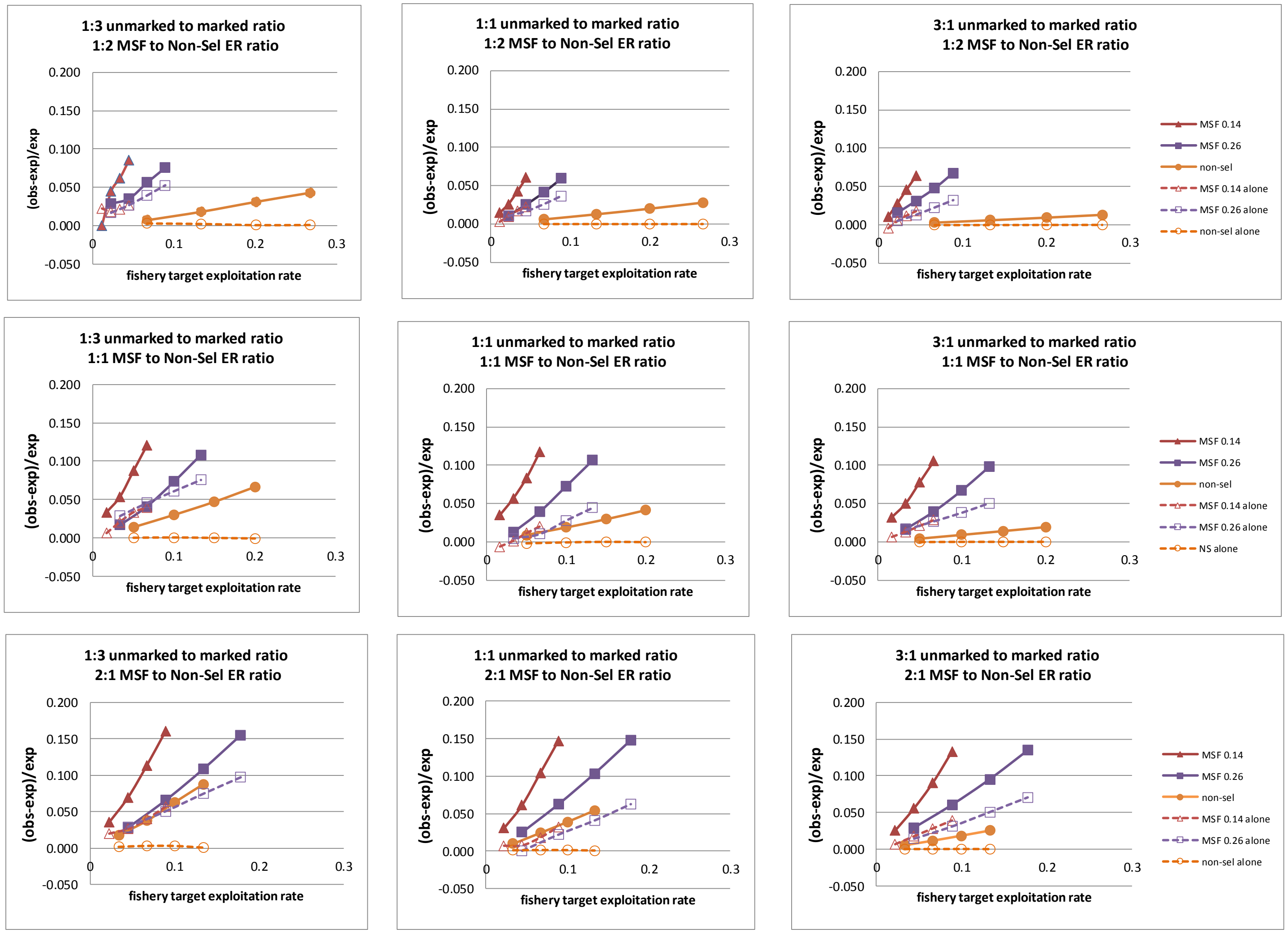


Figure 7. Bias in estimated unmarked exploitation rates in two MSF (δ = 0.14 and 0.26 respectively) and one non-selective fishery operating simultaneously and alone with landings, release mortality, drop-off, and mark and unmarked recognition errors as the sources of mortality. Note when the MSF-to-NSF exploitation rate ratios change, the target exploitation rates will also change.


1:3 unmarked to marked ratio
1:2 MSF to Non-Sel ER ratio

1:1 unmarked to marked ratio
1:2 MSF to Non-Sel ER ratio

3:1 unmarked to marked ratio
1:2 MSF to Non-Sel ER ratio

1:3 unmarked to marked ratio
1:1 MSF to Non-Sel ER ratio

1:1 unmarked to marked ratio
1:1 MSF to Non-Sel ER ratio

3:1 unmarked to marked ratio
1:1 MSF to Non-Sel ER ratio

1:3 unmarked to marked ratio
2:1 MSF to Non-Sel ER ratio

1:1 unmarked to marked ratio
2:1 MSF to Non-Sel ER ratio

3:1 unmarked to marked ratio
2:1 MSF to Non-Sel ER ratio

Figure 8. Bias in estimated unmarked exploitation rates in two MSF (*δ* = 0.14 and 0.26 respectively) and one non-selective fishery operating simultaneously and alone with landings, release mortality, drop-off, mark and unmarked recognition errors, increasing release mortality with successive encounters as the sources of mortality. Note when the MSF-to-NSF exploitation rate ratios change, the fishery target exploitation rates will also change.

Discussion

The unmarked-to-marked fish ratios in our simulations bracket those reported for historical mark-selective fisheries in Washington. If we had to choose, the 1:1 ratio would be closest to the 43% to 58% legal size Chinook marked encounter rate in Washington Marine Areas 5 and 6 between 2003 and 2009 (WDFW Multi-year Report Workgroup 2008, McHugh et al. 2009, and Baltsell et al. 2010). Similarly, the unmarked-to-marked coho encounter ratio in the 2009 recreational fishery off the coast of Washington was slightly greater than 1:1. A Chinook management area with the potential for simultaneous MSF and NSF would be Washington Marine Areas 3 and 4. Assuming the non-Indian troll and sport fisheries would be MSF and the treaty Indian troll fishery would be NSF, the 2010 catch quotas were approximately 17,000 and 25,000 respectively for the May-June time period and 16,000 and 26,000 for the July-September time period. The 1:1 unmarked-to-marked ratio and MSF < NSF scenario for Chinook corresponds to the upper middle panels in Figures 2-8. In coho fisheries off the Washington coast, most of the landings of marked coho occur in the MSF and the lower middle panels would be most representative of actual management scenarios.

Because all of the management models in use, FRAM, the Pacific Salmon Commission's Chinook Models, as well as the US v. Oregon Technical Advisory Committees Chinook harvest models require the accounting of all fishery-related mortalities, we focus our discussion on the upper middle panel of Figure 8 for Chinook, enlarged as Figure 9. Almost all of the historical target exploitation rates for individual Chinook MSF were less than 0.2 and our simulations were within that range. The biases for a MSF with a release-mortality rate of 0.14 (e.g., ocean sport) in a simultaneous fishery, was about three times greater than if the fishery was prosecuted in isolation. The difference in biases for a MSF with a higher release-mortality rate of 0.26 (e.g., ocean troll) was ambiguous at the lower exploitation rates, e.g., 0.01, and clearly greater at exploitation rates of 0.02 and higher. For example at a target exploitation rate of 0.07, the bias from being in a simultaneous fishery was 0.041, not quite double the 0.026 bias from being prosecuted alone. Finally, prosecuting a non-selective fishery in the same time step and area with one or more mark-selective fisheries will introduce a bias in the estimated mortalities where none existed if the same non-selective fishery was prosecuted alone. For coho, we turn our attention to the lower middle panel of Figure 8, enlarged as Figure 10. The results are similar to those for Chinook except there is no ambiguity in the differences between fishing simultaneous with other fisheries and fishing in isolation for the fishery with the higher, 0.26, release-mortality rate.

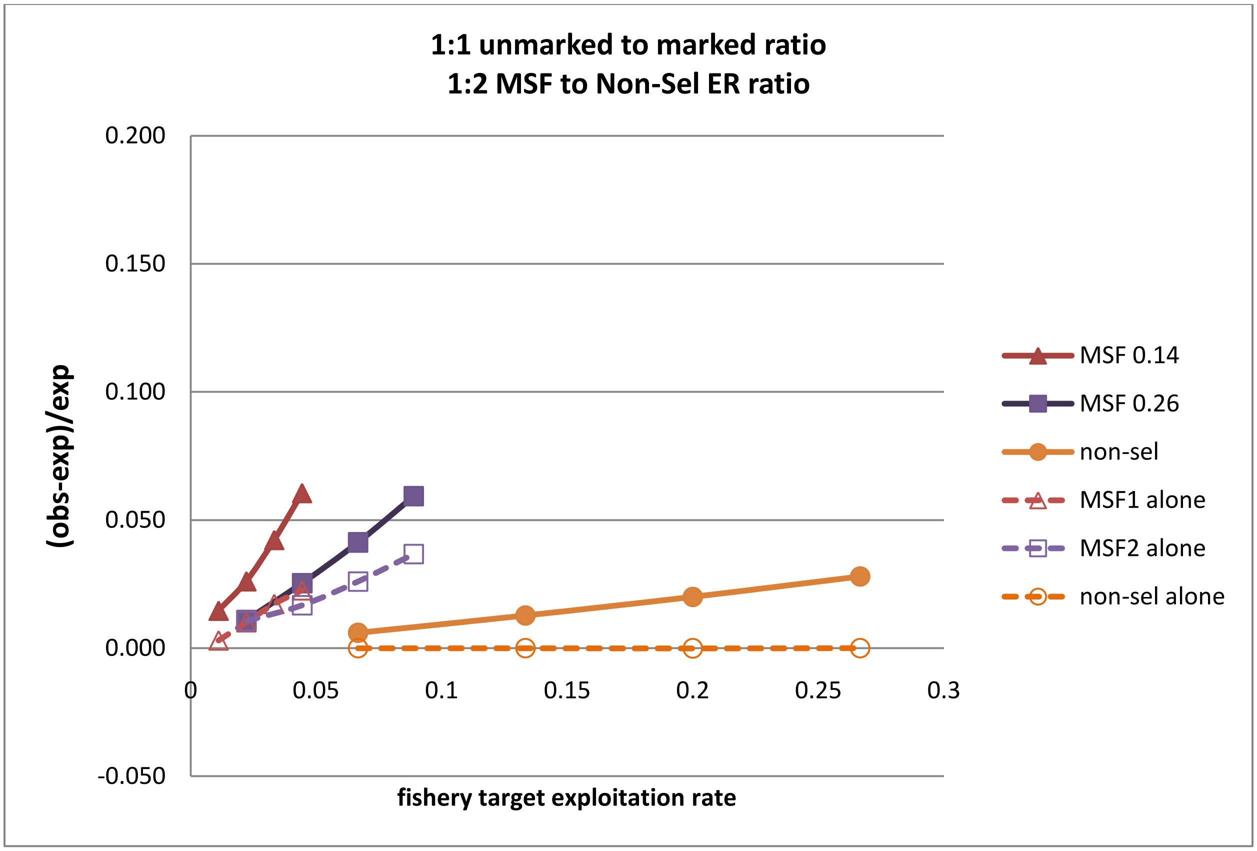


Figure 9. Scenario with unmarked-to-marked fish ratios close to 1 and MSF target exploitation rates less than that for the NSF is most representative of historical Chinook mark-selective fisheries.

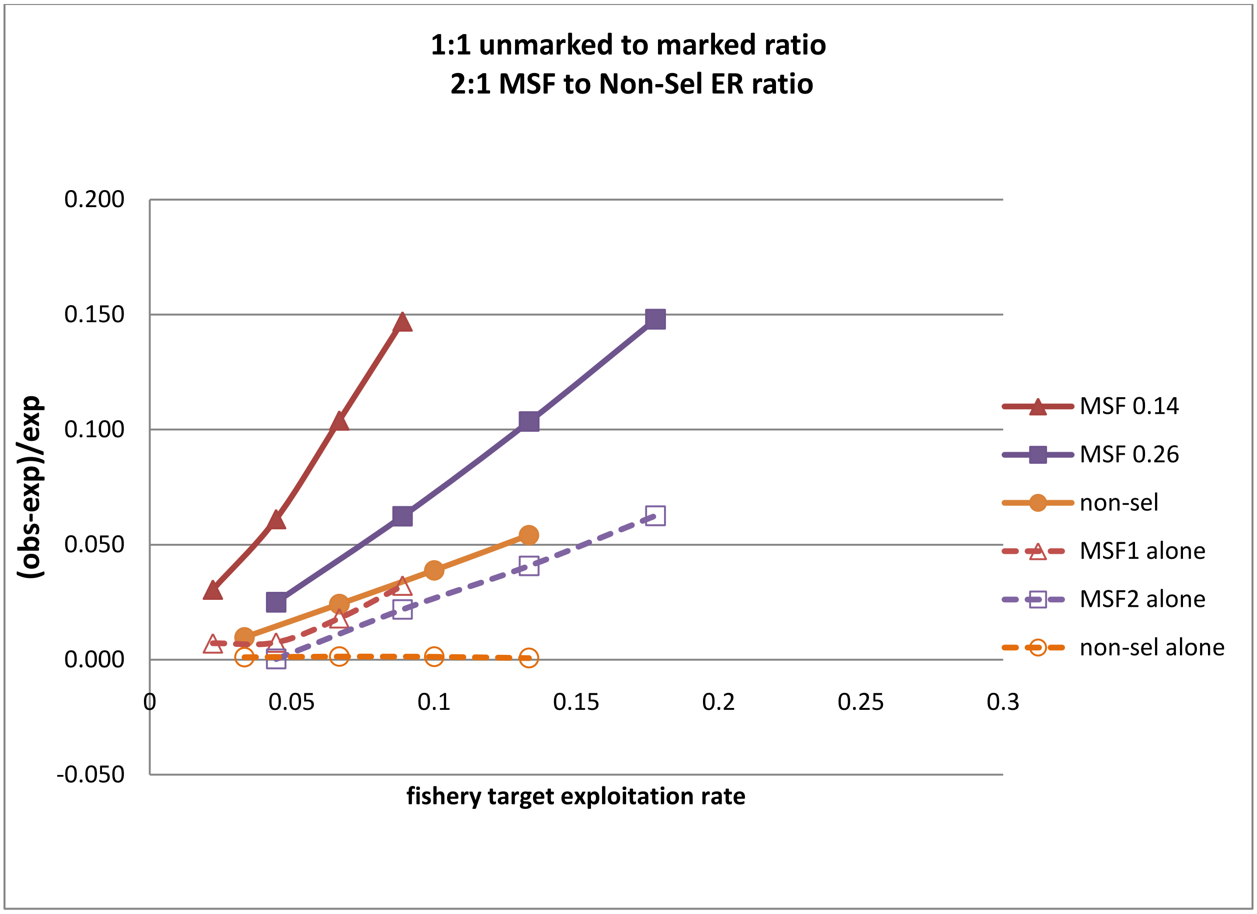


Figure 10. Scenario with unmarked-to-marked fish ratios close to 1 and MSF target exploitation rates greater than that for the NSF is most representative of historical coho mark-selective fisheries.

We had to solve for the mark-recognition error adjustment for marked fish released by mistake and unmarked fish landed by mistake because we were unable to describe the relationship between the mark-recognition error adjustment, *R*, γ and ζ. A weighted reciprocal of the recognition rates, $(M/\gamma + U/\zeta)/(M+U)$ works only when $\gamma = 0.95$ and $\zeta = 1$.

FRAM does not have the mark-recognition error adjustments for marked fish released by mistake and unmarked fish landed by mistake and its estimates of mortality would have been less than that estimated from Equation 10, especially at the lower exploitation rates, higher unmarked-to-marked fish ratios and higher MSF-to-NSF exploitation rate ratios. These latter two conditions are also not typical of historical mark-selective fisheries. If we used the FRAM model as our benchmark, some of the biases would have extended into the negative range as shown in Figure 11, creating a scaling problem when comparing simultaneous fisheries with isolated fisheries. Nevertheless, the trends are persistent and methods to correct the biases in the FRAM model are being proposed in a separate report.

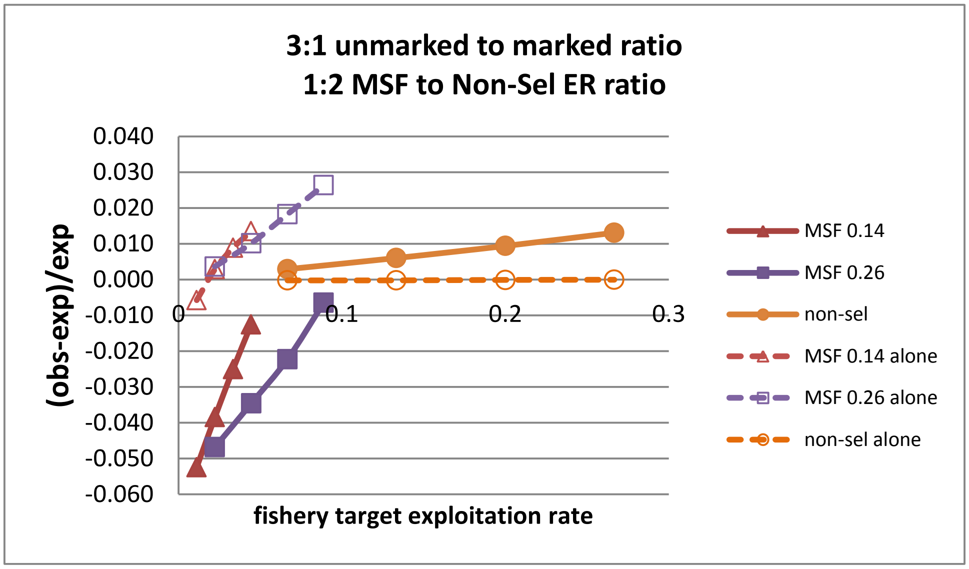


Figure 11. The FRAM model does not have a mark-recognition error adjustment for marked fish released and unmarked fish landed by mistake and therefore some of the estimated biases would be on the negative scale especially at the lower exploitation rates, higher unmarked-to-marked fish ratios and higher MSF-to-NSF exploitation rate ratios.

In the FRAM model there are multiple time steps, e.g., May-June, July-September, etc. At the end of each time step, natural mortality is applied to the escapement and the result is the starting cohort size for the next time period. The potential to propagate bias over multiple time steps will be investigated in a separate report.

Literature Cited

Ashbrook, C.E. 2008. Selective Fishing and Its Impacts on Salmon: A tale of Two Test Fisheries. M.S. Thesis. University of Washington.

Baltsell, M, S. Caromile, K. Kloempken, and L. Peterson. 2010. Marine Areas 5 and 6 Mark-Selective Recreational Chinook Fishery, Summer 2009 Post-season Report REVISED DRAFT, Washington Department of Fish and Wildlife. Olympia, Washington.

McHugh, P, M. Baltsell, K. Kloempken, and L. Peterson. 2009. Marine Areas 5 and 6 Mark-Selective Recreational Chinook Fishery, Summer 2008 Post-season Report REVISED DRAFT, Washington Department of Fish and Wildlife. Olympia, Washington.

Irvine, J.r. and M. Bradford. 2008. Declines in the Abundance of Thompson River Coho Salmon in the Interior of Southern British Columbia, and Canada's Coho Recovery Plan *in* L. M. Darling, editor. 2000. Proceedings of a Conference on the Biology and Management of Species and Habitats at Risk, Kamloops, B.C., 15 - 19 Feb.,1999. Volume Two. B.C. Ministry of Environment, Lands and Parks, Victoria, B.C. and University College of the Cariboo, Kamloops, B.C. 520pp.

Johnson, K.J. 1980 Regional overview of coded wire tagging of anadromous salmon and steelhead in Northwest America. American Fisheries Society Symposium 7:872-816.

Lawson, P. W., and D. B. Sampson. 1996. Gear-related mortality in selective fisheries for ocean salmon. North American Journal of Fisheries Management 16:512-520.

Nandor, G. F., J. R. Longwill, and D. L. Webb. 2010. Overview of the coded wire tag program in the Greater Pacific Region of North America. *in* Wolf, K.S., and O'Neal, J.S., eds., PNAMP Special Publication: Tagging, Telemetry and Marking Measures for Monitoring Fish Populations—A compendium of new and recent science for use in informing technique and decision modalities: Pacific Northwest Aquatic Monitoring Partnership Special Publication 2010-002, chap. 2, p. 5-46.

Pacific Fishery Management Council. 1999. Pacific Coast Salmon Plan. Pacific Fishery Management Council, Portland, Oregon.

Pacific Fishery Management Council. 2008. Fishery Regulation Assessment Model (FRAM) – an overview for Coho and Chinook. Pacific Fishery Management Council, Portland, Oregon.

Pacific Salmon Commission. 2005. Report of the expert panel on the future of the coded wire tag recovery program for Pacific salmon. Pacific Salmon Commission, Vancouver, British Columbia.

WDFW (Washington Department of Fish and Wildlife) Multi-year Report Workgroup. 2008. A multi-year assessment of the Marine Areas 5 and 6 selective Chinook fishery: 2003-2007, March 14, 2008, FINAL WORKING DRAFT , Washington Department of Fish and Wildlife. Olympia, Washington.