Future of the CWT Program: Challenges and Options
A Workshop June 7-10, 2004

Impact of Mass Marking and Mark-Selective Fisheries on use of CWT Data for Chinook and Coho Management

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1 Introduction

Mass marking and mark-selective fisheries present a problem for the coast wide CWT program and for the use of marked and tagged groups as representative of wild stocks. Historically, only CWT'd fish were marked with an adipose fin clip so that it was possible to visually identify landed fish for the presence of CWTs. The heads of clipped fish in samples for CWTs were taken and sent to specific labs for tag recovery (see background paper on Regional CWT program). Mass marking has now been instituted to provide a visual mark for hatchery production of coho and Chinook salmon and the decision was made to use the adipose fin clip. With mass marking, not all marked fish carry CWT's. Therefore, an adipose fin clip no longer provides information on the presence of tags and using it in visual sampling results in many untagged fish heads being needlessly sent to labs.

In addition the mass mark has provided an opportunity to selectively harvest clipped hatchery fish in mark-selective fisheries for coho and Chinook salmon. Marked and tagged fish have historically been use as representatives for wild stocks in the estimation of exploitation rates for use in management of PSC fisheries. With mark-selective fisheries, the exploitation rates on marked hatchery fish are purposefully greater than on unmarked natural stocks. Therefore, the marked and tagged fish can no longer be assumed to represent the unmarked natural stocks.

Alternative methods were needed to assess exploitation rates on unmarked natural stocks. This need led to the development of double index tag (DIT) groups where half the group was tagged and marked and the other half was tagged but not marked. The exploitation rates on the unmarked natural stocks could then be presumed to be the same as the unmarked half of the DIT pair, thus preserving the utility of the CWT system for assessing exploitation impacts on natural stocks. The two groups in a double index pair were required to be of the same size as the original index tag groups. And the two groups must be handled similarly in hatcheries during rearing and release and during tagging with the exception of the clip. Thus the assumption can be made that any difference between the two tag groups in a pair is only due to the mark and the selective fishery exploitation.

In order to avoid flooding the head labs with untagged fish, and to identify unmarked and tagged fish, electronic tag detection (ETD) equipment has been developed and put into use. ETD equipment can be stationary detectors that dead fish are passed through that are useful in many hatchery environments or hand-held wands that are useful for field samplers who must move around in their sampling efforts. Studies have shown that when used properly, the equipment can detect very close to 100% of the tags in the sampled fish.

However, some jurisdictions have elected not to use ETD, citing reliability or funding issues. Visual sampling continues to be the dominant sampling method in some places. The consequence is potential flooding of the head labs with untagged fish heads which results in higher costs and inefficiency. In addition, with the development of mark-selective fisheries and double index tagged (DIT) groups, tags from the unmarked DIT group will not be recovered from nonselective fisheries not sampled using ETD. If the number of unmarked and tagged mortalities cannot be estimated, then estimates of exploitation rates will be biased for the unmarked tagged DIT group.

With the additional management tool, mark selective fisheries, comes the need to assess incidental mortalities of unmarked fish in the mark-selective fisheries because they should be included in the exploitation rate estimates. The DIT groups provide a tool for estimating the unmarked encounters in mark-selective fisheries through the ratio of unmarked to marked fish (or λ) in the DIT pair. Several methods have been described for making estimates of these incidental mortalities (SFEC 2002). Each must make additional parameter assumptions about the unmarked-to-marked ratio and about the release mortality that increases the risk of biased estimates of exploitation rates. The degree of bias increases with the size of the mark-selective fishery.

2 Estimation of mortalities of unmarked tagged fish in mark-selective fisheries - methods summary

The methods developed for estimating the unmarked incidental hook and release mortalities are detailed in SFEC (2002) and are the same for both coho and Chinook salmon. They have also been applied to coho salmon with the results reported by the Joint Coho DIT Analysis Workgroup (2003). Two of the methods referred to as total methods (equal marine survival, EMS and equal exploitation rate, EER), require no assumptions in addition to those already made by current exploitation rate analysis and for the DIT group, but they are imprecise and without additional information can only assess the total incidental mortalities summed over all mark-selective fisheries. Two other methods are fishery specific (paired ratio, PR and terminal, TERM) and require additional assumptions, but are more precise and able to assess individual fishery mortalities. TERM was designed for terminal fisheries, PR for any fishery.

2.1 Total Methods

The total methods operate by estimating the unmarked cohort size and subtracting from that all estimated unmarked fish in non-selective fisheries and escapement. The difference is the mortality assigned to the suite of mark-selective fisheries. The two total methods differ in how the unmarked cohort size is estimated:

2.1.1 EMS – equal marine survival:

$$\underbrace{\frac{\#\text{ Unmarked Released}}{\#\text{ Marked Released}}\left(\text{Marked Cohort Size}\right)}_{\text{Estimate of Unmarked Cohort Size}} - \left(\text{Unmarked Recoveries from Fisheries}\right)$$

2.1.2 EER – equal exploitation rate method:

$$\underbrace{\frac{\#\text{ Unmarked in NSF}}{\#\text{ Marked in NSF}}\left(\text{Marked Cohort Size}\right)}_{\text{Estimate of Unmarked Cohort Size}} - \left(\text{Unmarked Recoveries from Fisheries}\right)$$

Because the unmarked to marked ratios estimated from non-selective fisheries (NSF's) are less precise than the ratios released from a hatchery, the estimated mark-selective incidental mortalities are less precise using the EER method vs. the EMS method. For example, in the coho DIT report (Joint coho DIT analysis Workgroup, 2003), the estimated percent standard errors for Forks Creek Hatchery coho (appendix tables 3.2.2 and 3.2.3) for the EMS method was 68% and for the EER method, the estimated percent standard errors was 425%.

2.2 Fishery specific Methods

While the PR and TERM methods provide fishery-specific mortality estimates, they require additional assumptions. Both methods operate by estimating the number of fishery encounters and then applying an incidental hook-and-release mortality rate (SFM) to those encountered.

2.2.1 TERM – Terminal Method:

$$\underbrace{(\text{Unmarked Terminal Run})*(\text{Harvest Rate in MSF})}_{\text{Estimate of Unmarked Encounters}}*(SFM).$$

The unmarked terminal run is calculated by dividing the estimated unmarked and tagged escapement by the terminal harvest rate as estimated for the marked and tagged fish. In the coho DIT report (Joint Coho DIT Analysis Workgroup, 2003) the TERM method was rarely used as it was deemed inappropriate because of assumption violations.

2.2.2 PR - Paired Ratio:

The PR method hold the most promise for offering the best precision, however its likely implementation will yield biased estimates. In general the estimator is given by:

$$\underbrace{(\text{Ratio of Unmarked to Marked Encountered})*(\text{Marked Recoveries in Fishery})}_{\text{Estimate of Unmarked Encounters}}*(SFM).$$

The ratio of unmarked to marked fish encountered for a DIT pair is obtained from an external source such as from hatchery release information, sample information from a nearby nonselective fishery or from hatchery escapement. The choice of external source of unmarked-to-marked ratio can affect the outcome; therefore it is logical to give some consideration to the three choices. Based on experience with coho DIT recoveries, the method using sample information from a nearby nonselective fishery, although unbiased or at least less biased that the other two methods yields quite imprecise results so that they are of questionable value.

The other two choices yield biased results but with more precision: hatchery release information yields unbiased estimates for the first mark-selective fishery but negatively biased estimates thereafter for both coho and Chinook. Hatchery escapement yields positively biased estimates if the mark-selective fishery is in a terminal area. However, if there are two mark-selective fisheries that are pre-terminal, then in some cases the direction of the bias will depend on how the stock is distributed relative to the mark-selective fishery and how those subpopulations mix after the fishery (see the coho DIT report). For example say the first mark-selective fishery is large, then the local population will exhibit a much larger unmarked-to-marked ratio than the population at large after the first fishery. Then, let the second mark-selective fishery occur on the same local population with the newer but much larger unmarked-to-marked ratio. Now, consider that after the second mark-selective fishery, some of the survivors mature along with a large proportion of maturing fish from other subpopulations that were not vulnerable to either mark-selective fishery. Then, it is possible that the hatchery escapement ratio is too low for the second mark-selective fishery so that the direction of the bias may not be clear, but will be dependent on how the fish distribute, which portions are vulnerable to the mark-selective fisheries,and how the maturation occurs.

Although the exact bias is unknown, when it can be argued that the hatchery escapement information yields positively biased estimates then the difference in the estimate based on hatchery release vs. hatchery escapement can give one an idea of boundaries on the size of the bias. Although bias is not generally as estimable quantity, information on the maximum size of the bias can help determine if the improvements in precision offset the cost in bias. The following example demonstrates this concept.

2.3 Example: Salmon River Coho (age 3) 1997 Brood Year (data from Joint Coho DIT Workgroup, 2003).

In this example, let the task be to estimate the unmarked mortalities of all mark-selective sport fisheries combined. Excluding the troll mark-selective fisheries simplifies matters since the sport fisheries share the same incidental hook-and-release mortality rate. The summarized data for the mark-selective fisheries used by all three methods are given in Table 1.

Table 1. Summary of Marked DIT recoveries in sport mark-selective fisheries in 2000 for Salmon River coho, brood year 1997.

Mark-Selective Sport Fishery	Marked DIT Mortalities (M)	Standard Error of M	Default hook and release mortality
Coos Bay Sport	1.74	1.13	0.14
Tillamook Sport	1.2	0.49	0.14
WA Area 1 Sport	25.33	5.31	0.14
WA Area 2 Sport	66.25	9.24	0.14
WA Area 3 Sport	3.58	0.84	0.14
WA Area 4 Sport	8.65	4.04	0.14
	$\sum M = 105.01$	$V\left(\sum M\right) = 132.12$	

2.3.1 Estimation method using hatchery release unmarked-to-marked ratio

The hatchery release ratio for that DIT group was 0.9446 with 68,234 unmarked DIT fish released and 72,236 marked fish released. Given the release information and the information in Table 1, the estimate and standard error of the total unmarked mortalities are:

$$\sum U^{MSF} = \left(\sum M^{MSF}\right)\lambda^{REL} sfm = 105.01 * 0.945 * 0.14 = 13.89 \text{ and}$$
$$SE\left(\sum U^{MSF}\right) \cong \sqrt{V\left(\sum M^{MSF}\right)\left(\lambda^{REL}\right)^2 sfm^2} = \sqrt{132.12} * 0.945 * 0.14 = 1.52$$

2.3.2 Estimation method using non-selective fishery unmarked-to-marked ratio

One choice for a nearby nonselective fishery is the Washington Area 4,4B Troll fishery. In 2000, there were 7.48 estimated marked DIT recoveries for brood year 1997 (with standard error 6.96) and 7.48 estimated unmarked DIT recoveries (with estimated standard error 6.96). With these data the estimate and standard error of the total unmarked mortalities are:

$$\sum U^{MSF} = \left(\sum M^{MSF}\right)\lambda^{NSF} sfm = 105.01 * 1.0 * 0.14 = 14.7 \text{ with}$$
$$SE\left(\sum U^{MSF}\right) \cong \sqrt{\left(\sum M^{MSF}\right)^2 \left(sfm^2\right) V\left(\lambda^{NSF}\right) + V\left(\sum M^{MSF}\right)\left(\lambda^{NSF}\right)^2 sfm^2}$$

$$\text{where } V\left(\lambda^{NSF}\right) \cong \left(\frac{1}{\sum M^{NSF}}\right)^2 V\left(\sum U^{NSF}\right) + V\left(\sum M^{NSF}\right)\left(\frac{\lambda^{NSF}}{\sum M^{NSF}}\right)^2$$

$$\text{so that } V\left(\lambda^{NSF}\right) \cong \left(\frac{1}{7.48}\right)^2 48.44 + 48.44\left(\frac{1}{7.48}\right)^2 = 1.73 \text{ and}$$

$$SE\left(\sum U^{MSF}\right) \cong \sqrt{(105.01)^2 \left(0.14^2\right) 1.73 + 132.12 (1.0)^2 \left(0.14^2\right)} = 19.53$$

2.3.3 Estimation method using hatchery escapement unmarked-to-marked ratio

This method is similar to that of using the nonselective fishery, except that the hatchery escapement plus spawning ground recoveries yield the unmarked-to-marked ratios that replace those of the nonselective fishery. In 2000, an estimated 611.6 marked DIT coho escaped with a variance of 22084 and an estimated 856.5 unmarked DIT fish escaped with a variance of 26591. With those data, we have an escapement unmarked-to-marked ratio of 1.4 so that

$$\sum U^{MSF} = \left(\sum M^{MSF}\right)\lambda^{ESC} sfm = 105.01 * 1.4 * 0.14 = 20.58 \text{ and}$$
$$SE\left(\sum U^{MSF}\right) \cong \sqrt{\left(\sum M^{MSF}\right)^2 \left(sfm^2\right) V\left(\lambda^{ESC}\right) + V\left(\sum M^{MSF}\right)\left(\lambda^{ESC}\right)^2 sfm^2}$$

$$\text{where } V(\lambda^{ESC}) \cong \left(\frac{1}{M^{ESC}}\right)^2 V(U^{ESC}) + V(M^{ESC})\left(\frac{\lambda^{ESC}}{M^{ESC}}\right)^2 .$$

Then,

$$V(\lambda^{ESC}) \cong \left(\frac{1}{611.64}\right)^2 26591 + 22054\left(\frac{1.4}{611.64}\right)^2 = 0.187$$

and

$$SE\left(\sum U^{MSF}\right) \cong \sqrt{(105.01)^2(0.14^2)0.187 + 132.12(1.4)^2(0.14^2)} = 6.74$$

2.4 Precision versus bias.

Assuming a normal distribution for the estimators, the different methods yield the distributions shown in Figure 1.

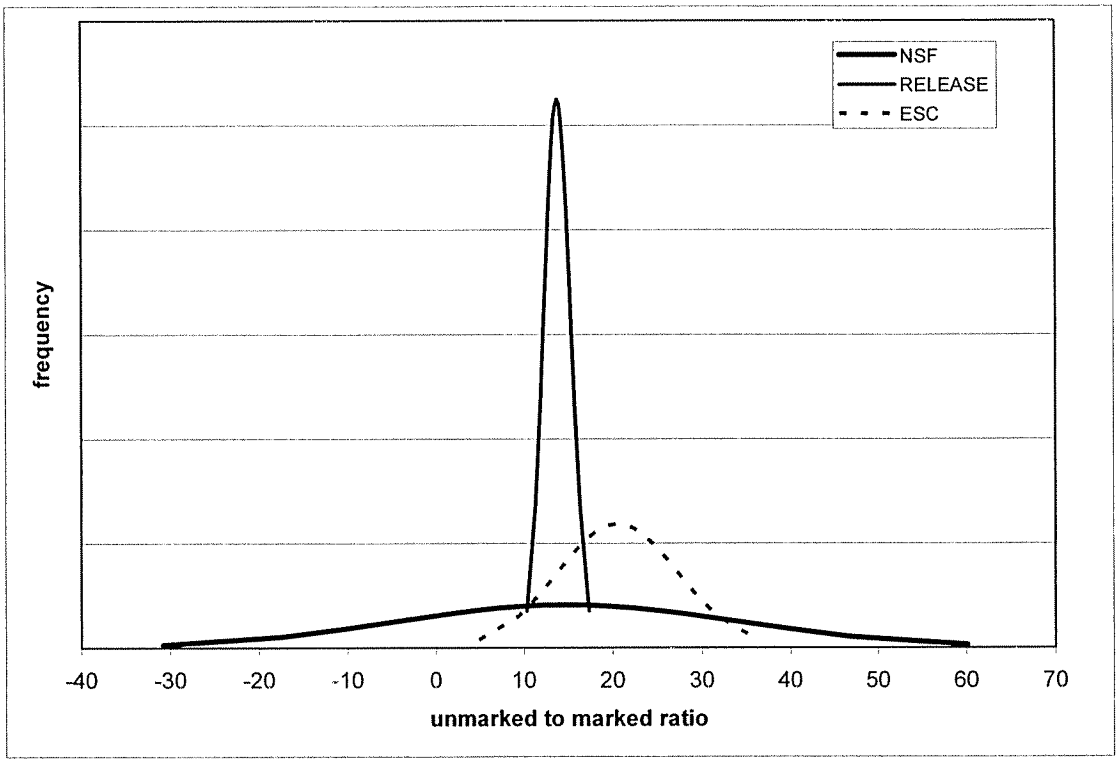

Figure 1. Frequency curves, assuming normal distributions, for the three paired ratio estimators (NSF, RELEASE, and ESC) of unmarked DIT mortalities for Salmon River coho brood year 1997 in 2000 sport mark selective-fisheries.

One estimate of the upper bound on the bias is $\hat{U}^{ESC} - \hat{U}^{REL} = 6.7$ fish. This bias can be incorporated into confidence intervals based on mean squared error (to show its full impact) using the formula in Table 2.

Table 2. Incorporation of bias into confidence interval bounds.

	Confidence Interval Lower Bound	Confidence Interval Upper Bound
Negatively Biased Estimator	$\hat{U} - 2\sqrt{Bias^2 + Var}$	$\hat{U} + 2\sqrt{Var}$
Positively Biased Estimator	$\hat{U} - 2\sqrt{Var}$	$\hat{U} + 2\sqrt{Bias^2 + Var}$
Unknown Bias Direction	$\hat{U} - 2\sqrt{Bias^2 + Var}$	$\hat{U} + 2\sqrt{Bias^2 + Var}$

These formula give the following confidence intervals for unmarked mortalities for the three different choices of unmarked to marked ratio (Table 3).

Table 3. Estimated unmarked mortalities with confidence interval based on MSE.

Source of ratio λ	Estimated unmarked mortalities	95% confidence interval using MSE
Release	13.89	10.86 - 27.62
Escapement	20.58	1.58 - 34.06
Non-selective fishery	14.70	-24.36 - 53.76

These are all overlapping confidence intervals and there is no significant difference amongst the estimates using the three ratios, but the estimate using λ^{Rel} provides the most precise estimate.

2.5 Coho vs Chinook Salmon

Estimation of mortalities of unmarked and tagged fish in mark-selective fisheries presents a problem, many of which are discussed in the section above for Salmon River coho salmon. Coho salmon are a species which largely matures as three-year olds and the bulk of fishery harvest is for this age. As they are migrating to the spawning grounds they will pass through fisheries, selective and non-selective. The use of the unmarked to marked ratio at release and escapement to define the potential bias assumes this behavior. It assumes that the ratio will basically increase monotonically from release to escapement. The change in λ can be illustrated as a straight line as seen in Figure 2 path D, which assumes that all fish are equally vulnerable to the mark selective fisheries (SFs).

Chinook salmon differ from coho salmon in that they mature at multiple ages and the historical tag data indicate that they can have a sub-group type of geographic distribution. All sub-groups are not equally vulnerable to all fisheries. This complicates the use of DIT for estimation of mortalities of unmarked and tagged Chinook salmon. Figure 2, path C shows where one sub-group may be subject to mark selective fisheries, then prior to escapement mix with another sub-group that was not vulnerable to these fisheries, with the resulting ratio at escapement possibly being lower than the ratio in the fishery. In this scenario both the ratio at release and escapement would be underestimates for some mark selective fishery ratios.

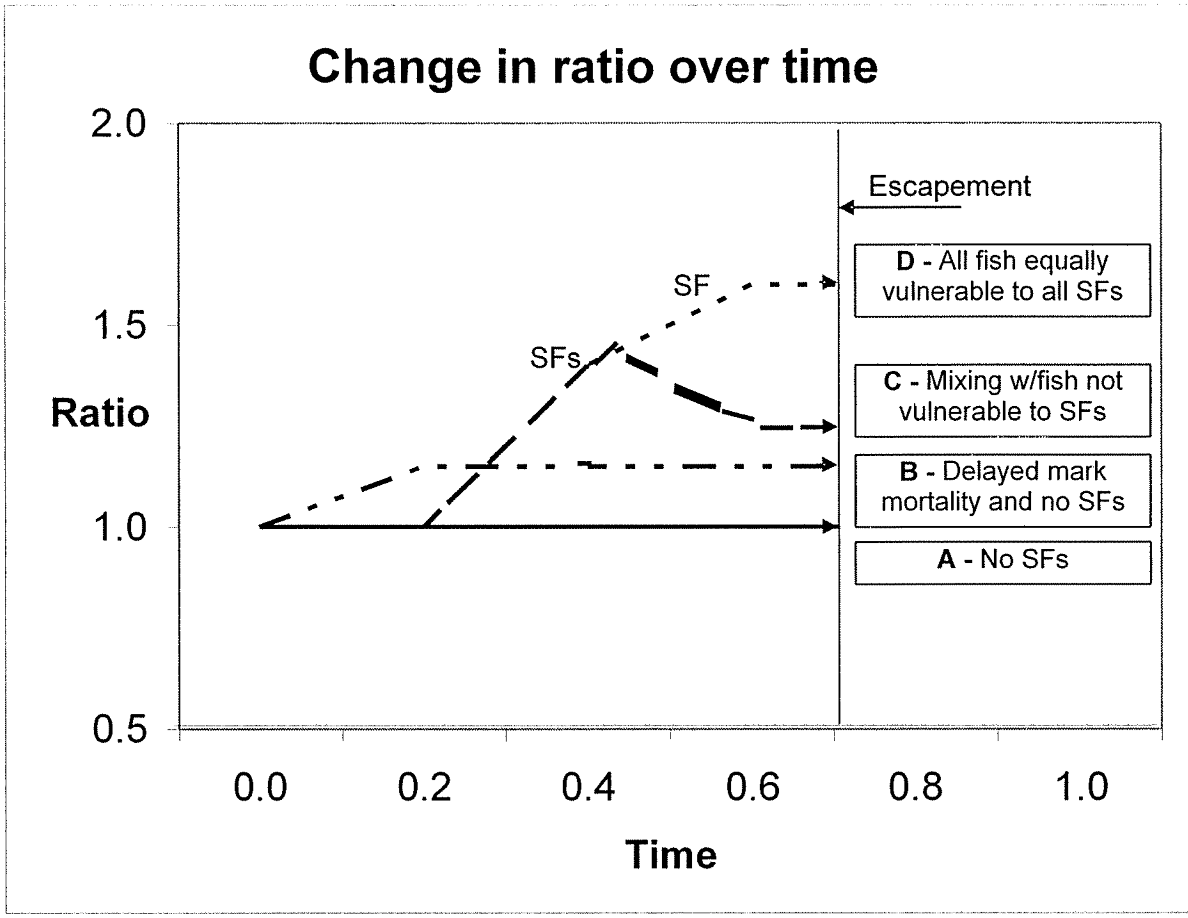

Figure 2. General schematic illustrating the potential change in the unmarked-to-marked ratio (λ) over time (starting with $\lambda^{Rel} = 1$) for a migration occurring within a single year (e.g., age 3 coho salmon) under several scenarios (with and without mark-selective fisheries and with no selective fishery but with delayed mark mortality). λ will increase with each new mark-selective fishery (SF) that impacts the stock. λ will increase if there is a delayed mark mortality effect. Furthermore, λ can decrease locally if fish from a DIT group that were not subjected to mark-selective fisheries enter the area and thereby "dilute" λ.

2.6 The Need for DIT when using the PR method with λ^{REL}

In constructing the estimates of unmarked mortalities in a mark-selective fishery when using the PR method with the unmarked-to-marked ratio at release, the unmarked half of the DIT is not used. In fact, the calculated unmarked exploitation rate for the mark-selective fishery will be equal to the marked exploitation rate multiplied by the incidental hook-and-release mortality rate:

$$ER^{U,MSF} = \frac{U^{MSF}}{Unmarked\ Cohort} = \frac{U^{MSF}}{Marked\ Cohort * \lambda^{REL}}$$
$$= \frac{M^{MSF}\lambda^{REL} * sfm}{Marked\ Cohort * \lambda^{REL}} = ER^{M,MSF} sfm.$$

This outcome may raise the question of the need for DIT tagging (the unmarked fish) if the PR with λ^{REL} were to become the standard method of analysis, particularly if those efforts could be rechanneled into expanding the tagging and recovery programs for marked fish. Eliminating DIT would bring some relief to agencies that struggle to recover CWTs from unmarked fish. However, without the unmarked portion of DIT tagging and recovery efforts, other useful monitoring information would be lost and those impacts should be considered.

- DIT allows one to use both estimates using λ^{REL} and λ^{ESC} to make data-based estimates of the upper bounds of the bias when λ^{ESC} yields positively biased estimates. Without DIT, the size of bias in unmarked mortalities would need to be inferred through simulation efforts.

- DIT allows one to monitor the mark-selective impact by comparing the proportion of unmarked and marked DIT fish returning to the hatchery racks. Although these proportions were not particularly informative for coho (see coho DIT report), as the exploitation rates of mark-selective fisheries grow, these comparisons may be quite useful as a monitoring tool.

- Without DIT, the exploitation rates for unmarked fish in non-selective fisheries will be biased. DIT allows one to recover unmarked CWT's from non-selective fisheries for calculating their exploitation rates. Without DIT, the unmarked exploitation rates would be set equal to that of the observed marked exploitation rate. However, because mark-selective fisheries are expected to remove proportionally more marked than unmarked fish from the population, one would expect greater unmarked exploitation in non-selective fisheries than for marked fish.

  As one can see from Table 4, without DIT, the exploitation rates on unmarked fish are biased low in the non-selective fisheries as well as biased high for the mark-selective fisheries (except for the first mark-selective fishery). With DIT, all the unmarked exploitation rates are biased, but less so than without DIT.

Table 4. Simulated results showing differences in calculated unmarked exploitation rates with and without DIT, assuming λ^{REL} = 1.0 and an *sfm* = 0.10.

Fishery	True Marked Mortalities (*M*)[/1]	True Marked Exploitation Rate	True Unmarked Mortalities (*U*)	True Unmarked Exploitation Rate	Estimated Unmarked Mortalities (est'd U) w/DIT[/1]	Estimated Unmarked Exploitation Rate w/DIT	Estimated Unmarked Exploitation Rate w/o DIT
	(remaining**HR*)	*M*/(marked cohort)	(remaining**HR***sfm*)	*U*/(true unmarked cohort)	$M^{*}\lambda^{REL}{*}sfm$	(est'd U)/(est'd unmarked cohort)	$ER^{M}{*}sfm$
Initial Cohort Size	1000		1000		998.65		
MSF 1 HR = 0.15	150	0.15	15	0.015	15	0.015	0.015
# remaining	850		985				
MSF 2 HR = 0.10	85	0.085	9.85	0.00985	8.5	0.0085	0.0085
# remaining	765		975.15				
NSF 1 HR = 0.20	153	0.153	195.03	0.195	195.03	0.1953	0.153
# remaining	612		780.12				
NSF 2 HR = 0.10	61.2	0.612	69.15	0.06915	69.15	0.0692	0.0612
# remaining	550.8		710.97				
Escapement	550.8		710.97		710.97		

[/1] The shaded boxed numbers are observable.

3 References

Joint Coho DIT Analysis Workgroup. 2003. Analysis of coho salmon double index tag (DIT) data for the brood years 1995-1997. Northwest Fishery Resource Bulletin. Project Report Series No. 12. pp. 160.

SFEC. 2002. Investigation of methods to estimate mortalities of unmarked salmon in mark-selective fisheries through the use of double index tag groups. TCSFEC(02)-1. pp. 87