The accuracy of estimates of life-history and fishery parameters derived from CWT or PBT data depend on two principal factors: 1) the number of tags that are actually recovered, and 2) the accuracy with which those tags can be expanded into estimates of the total number of release group fish represented by those recoveries. We address the question of errors of estimation by evaluating each of these factors.

**Number of Tag Recoveries**

Ultimately, errors of estimation for a specific stock or release group are reduced as tag recoveries from that stock or release group are increased under either a CWT or PBT system. Tag recovery rates in turn are a function of the number of tags deployed and the sampling intensity. As per-fish tagging costs using PBT are lower than for CWTs, implementation of PBT would likely allow increased tagging rates for many stocks, which would reduce errors of estimation *if* sampling rates were held constant and the additional fish tagged were also marked such that they would be recovered in later sampling.

However, alterations in marking, tagging, and sampling rates may interact in complicated ways and have consequences that are not always immediately obvious. For example, increasing the tagging and marking rates on stocks that are only rarely encountered in subsequent sampling would increase the information available on such stocks with little increase in the overall burden on the sampling system, but increasing the tagging and marking rates on stocks that already make up a large number of recoveries could lead to substantially increased sampling costs with marginal information benefits for these larger stocks, and this might create financial pressure to reduce the overall sampling intensity and thus the tag recovery rate for small and rare stocks.

Optimization of the marking, tagging, and sampling rates would need to be done with careful consideration of individual stocks and the constraints on tagging, marking, and sampling each in the context of a larger coastwide sampling scheme. Fully addressing this issue is beyond the scope of this report. Exploration of the effects on recovery rates from changes to the current levels of marking, tagging, and sampling rates could be done using existing systems such as PlanIt! (Morishima et al. 2012).

**Uncertainty in Expansion Factors**

We note that the PBT + AWT “System 1” in section II.A would essentially duplicate the number of stock-specific tag recoveries of the current CWT system. This is a good reference point from which to consider the additional factors affecting errors of estimation between PBT and CWT. The qualitative differences between CWT and PBT as they affect errors of estimation are as follows:

1) PBT tagged fish from which tissues are sampled in fishery or escapement areas may not yield successful (scorable) genotypes, and thus render their release group of origin unknown. However the rate of genotyping failures can be quantified, and so long as the probability of such failure is not stock-dependent, can be dealt with using expansion factors the same way as is done for unreadable CWTs or cases where CWTs are lost while attempting to extract them from the fish.

2) Assignment of offspring to parents may be subject to either false positive errors (a sampled fish is assigned to a parent that is not its true parent) or false negative errors (a sampled fish has parents in the database, but is not assigned to them). With a sufficient number of genetic markers, such rates are typically low; however, there is a tradeoff: setting stringent assignment criteria in order to reduce the occurrence of false-positive errors will necessarily lead to a higher rate of false negative errors (Anderson & Garza 2006). Since there is no obvious way of correcting sample recovery estimates for false positive errors (since they are difficult to detect), it will usually be best to minimize them, and account for false negatives using expansion factors in the same manner that CWT tag loss is accounted for. Currently there is not a standardized way of estimating false negative rates in a particular fishery, though they can be predicted for a particular population using estimated genotyping error rates, the allele frequencies in the population, and knowledge of the degree of relatedness within the population. For PBT, it will be necessary to develop and agree upon a defensible method of estimating the false negative rate.

3) There is some uncertainty in the tagging rate achieved through PBT, due to the variance in family size, if scorable genotypes were not obtained from all the parents of the release group. If mating pairs are unknown, there is additional uncertainty in the tagging rate because it is unknown how many matings the ungenotyped parent(s) participated in. Appendix Y addresses the first of these two issues in detail, but the main findings are summarized below.

When considering the uncertainty in the PBT tagging rate, it is important to realize that even in the case of a CWT release group, where the tag rate is estimated based on a count of tagged versus untagged individuals, the tagging fraction of *adults* may differ slightly from this tagging rate due to the stochastic nature of individual survival and the fact that it is unlikely that the *exact* proportions of tagged versus untagged individuals will survive to adulthood, even if there is no tagging effect on the probability of survival. With CWTs (and with PBT), the variance in the adult tagging rate varies inversely with the size of the release group. However, with PBT, the situation is more complex because survival to adulthood typically is correlated with family. Were the number of surviving adults per family to be Poisson distributed with constant mean, then this correlation between family and survival would not be an important factor. However, salmon populations tend to exhibit overdispersion in family size making the effect of family-specific survival relevant to the question of uncertainty in the tagging rate. Accordingly the use of PBT for tagging has the potential to increase the variance in realized tagging rates.

The practical implications of this increased variance, however, must be evaluated in the context of the total variance of estimates obtained by sampling expansions. In many cases, the variance due to sampling only a small fraction of each release group far outweighs the additional variance from PBT-tagging rate variance.

Appendix Y describes simulations exploring the role of three main factors influencing the variance in the realized PBT tagging rate: 1) the variance in family size (which can be expressed in terms of the ratio of the effective number of spawners to the actual number) amongst the spawners contributing to a release group; 2) The number of families (distinct parent pairs) used to produce the juveniles in the release group; and 3) the fraction of parent pairs contributing to the release group whose offspring are successfully tagged, which, in turn, is a function of the fraction of the parents of the release group for which successful genotypes were obtained. However, the influence of the variance of the realized PBT tagging rate on expanded estimates of the total number of release group fish represented by tag recoveries is dependent on the rate of sampling in the recovery areas. When the fraction of fish from a release group recovered is expected to be less than 25 or 50% of the total present in the recovery area, there are many cases in which the extra uncertainty due to variance in realized PBT tagging rate is negligible compared to the large amount of uncertainty due to the sampling rate.

The simulations indicate that all four of the following conditions must be met in order for the variance in PBT tagging rates to create noticeable decreases in accuracy of PBT-based estimates of expanded fish numbers:

1. Release groups are composed of offspring of fewer than 30 parent pairs.
2. The ratio of the effective number of spawners to the actual number of spawners contributing to a release group is lower than 0.88.
3. More than 50% of all the fish from a release group present in a recovery area are expected to be sampled.
4. Fewer than 96% of families contributing to a release group are successfully tagged via PBT.

Appendix Y should be consulted for the magnitude of the effects of changes in each of these conditions.

In connection with condition #4, it is expected have and hence have offspring that are tagged With sufficient markers to perform single parent assignments, however, the fraction of tagged families decreases much more slowly with the fraction of successfully genotyped parents, because both parents of a family must be unsuccessfully genotyped for the offspring to remain untagged. For example, even if only 86% of male and female spawners are successfully genotyped, the tagging rate of their offspring is still expected to be higher than 98% (see also Section II.B).

Appendix Y describes data and analyses used to determine how frequently the above four conditions are likely to be encountered given the practices in current tagging and sampling programs. In summary:

* Condition 1 may be encountered frequently. Approximately 33% of release groups in the last decade were small enough that they could have been produced by fewer than 10 parent pairs.
* Condition 2 is usually encountered. Data from hatchery programs suggest that the ratio of effective to actual number of spawners can be expected to be between 0.3 and 0.7 in salmon hatcheries.
* Condition 3 is infrequently encountered in ocean fisheries. Only a small fraction of CWTs are recovered in situations where the sampling rate on tagged fish from the release group exceeds 50%. However, a much higher fraction of fish may be sampled in terminal recovery areas.
* Empirical data from a five-year old PBT program in Idaho (Appendix The SNAKE RIVER EXPERIENCED) indicates that the rate of individual genotyping success can be maintained at a level near 98%. With such rates, using parent-pair assignments for parentage yields a family tagging rate of near 96%. However, using single parent assignments, this genotyping success rate would yield family tagging rates of effectively 1.0, at which point the variance in realized PBT tagging rate is effectively 0.

In conclusion, the additional variance in estimates of fishery and life history parameters incurred due to variance in realized PBT tagging rates is likely to be negligible in a PBT program capable of making accurate assignments to single parents.

Other Considerations

Related to the increase in PBT tagging rate variance due to variance in family size is the additional complication that PBT tagging might place upon studies designed to identify survival rate differences between different release groups. Under PBT, a test for a significant difference in survival rate will have to separately account for differences that are possibly due to random family effects versus those due to treatment effects. Consequently, PBT-based studies will likely require larger release groups within each treatment to ensure that each treatment is represented by an adequate number of distinct families. Furthermore, it would likely be useful to adopt new statistical analysis methods that use the observed distribution of recovered family sizes to account for the additional family-based variance in the studies. On the other hand, such PBT-based study designs might make it possible to detect treatments that increase the variance in family size, thus approaching the question of whether there may be treatment-by-family interactions.