Independent Scientific Advisory Board
for the Northwest Power and Conservation Council,
Columbia River Basin Indian Tribes,
and National Marine Fisheries Service
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Review of the Independent Economic Analysis Board's model and documentation: *"Cost-Effectiveness of Fish Tagging Technologies and Programs in the Columbia River Basin"*

(Review of the IEAB Fish Tagging Cost Effectiveness Model)

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ISAB Review of the IEAB Fish Tagging Cost Effectiveness Model

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Summary

In response to the Northwest Power and Conservation Council's June 2013 request, the ISAB reviewed the Independent Economic Analysis Board's model and documentation: *Cost-Effectiveness of Fish Tagging Technologies and Programs in the Columbia River Basin* (IEAB document 2013-1). The IEAB Fish Tagging (FT) model is a non-linear mathematical programming model that determines how many (juvenile) fish should be tagged with what type of tags (CWT, PIT, genetic) to satisfy a set of required outcomes, such as a minimum number of tags of each type detected/recovered at certain locations or indicators. The model can be used to evaluate tradeoffs in using different tag types and to search for cost efficiencies in the numbers and geographic locations where fish are tagged.

Overall, the IEAB report is thoughtful and well written. The objectives of the modeling effort are explained well and, for the most part, the assumptions of the model (such as survival rates) are given along with the rationale for the assumptions. However, the methods are not fully explained. Providing some of the model equations would have been helpful in the ISAB's review.

The model provides a cost-effectiveness analysis given the minimum number of tags that must be detected or recovered for an indicator (e.g., smolt-adult return rate) addressing a specific management question (e.g., is the stock self-sustaining). However, the model cannot explore alternative tagging options to optimize the total value of the information collected. This is because the model would first require assigning relative values to the different indicators in the tagging programs. For example, an estimate of reach survival to Bonneville for smolts from stock X must be ranked as more or less valuable than an estimate of smolt-to-adult-return (SAR) survival for stock Y. Nevertheless, the model can incorporate the relative values of indicators in an indirect way by changing the required number of tags detected/recovered for each indicator, which is analogous to saying that some indicators should be ranked as more valuable than others when estimates are more precise.

The model is deterministic – it always arrives at the same outputs given the same inputs – and uses average values of various parameters such as in-river survival or ocean survival. However, there is often a large variation in parameter values among years and among stocks. Consequently, several sensitivity analyses are required. For example, the model should be run under poor survival conditions to see if the conclusions are robust. Further, cost estimates are imprecise and are constantly changing, especially with genetic sampling, and multiple modeling runs should be made to identify the price points at which conclusions would change.

The current model examines cost effectiveness, but not program effectiveness. Examining program effectiveness requires managers to determine and rank the information needed for

the indicators and then estimate the numbers of tagged fish needed to achieve the management objectives, including those stocks protected by the Endangered Species Act (ESA). Tag numbers and tag types would be determined at the project level and tradeoffs between tag numbers, tag costs, and precision of the metric of interest could then be investigated. The ISAB did not participate in the recent 2012-2013 Fish Tagging Forum, but the ISAB agrees that cost efficiencies should be evaluated with respect to the needs of each project that depends on tagging program effectiveness. The IEAB report discusses the need for regional coordination and rationalization of tagging efforts to gain greater cost-effectiveness and program effectiveness but makes no explicit recommendations.

The ISAB offers several recommendations toward further development of the IEAB model to improve its usefulness for fish management in the Columbia River Basin. Specifically:

- Incorporate elements to evaluate program effectiveness. This requires all parties involved in the Columbia River Basin fish programs collaborate in developing a priority list of the many indicators (more than 100) identified by the IEAB. This difficult exercise is needed to ensure that tagging programs provide information for critical stocks, for treaties, or for unforeseen events such as very low survival or hatchery related problems.
- Focus on rationalization of the PIT-tagging program given the very large detection infrastructure already in place and the overlapping objectives of the different tagging studies (e.g., estimating in-river and transport survival, evaluating effectiveness of habitat improvements, measuring straying rates, and so forth). This evaluation should also consider tradeoffs between adding more fixed costs to improve detection rates by modification of infrastructure vs. ongoing costs and handling effects of tagging more fish.
- Incorporate otolith marking and acoustic tagging methods in the model. Otolith marking programs can mark 100% of hatchery fish at relatively small costs, while acoustic tags can have a very high detection efficiency (see Melnychuk 2012), which imply much fewer fish need to be tagged.
- Incorporate synergies between different tag types, especially genetic methods. Genetic methods are expected to undergo great technological improvements in the near future and often provide complementary information to other tag-types.

Responses to Review Questions

The IEAB welcomed the review and posed eight detailed questions to the ISAB for feedback to improve future modeling efforts. The ISAB was aided in its review by an informative and much appreciated presentation on the modeling effort by IEAB member Bill Jaeger at the ISAB's July 2013 meeting.

1. *There are assumptions reflected in the model that should be validated, and likely modified and improved. The assumptions deserving examination include:*
    a. *Size of populations (average number of smolts) for each stock (hatchery and especially native) originating in each of the 64 subbasins (river segments) in the model (Tables A1 and A2).*
    b. *Mortality rates by river reach, dam passage, juvenile and adult (Page 33).*
    c. *Ocean mortality rates by stock (Page 33)*
    d. *Mortality from tagging (Page 34)*

    What approach to validating these assumptions would the ISAB recommend? Can the ISAB provide such review? If so, are the assumptions (to be provided) appropriate as a most-likely condition? Is there a reasonable range of values to consider, and if so, what should that range be?

The IEAB report describes, in Appendix A, parameter values used in various parts of the model in general terms. A detailed validation of the parameter values used in the IEAB analysis is beyond the scope of this ISAB review, as this would require a detailed examination of the whole model. However, the values provided in the reports and web sites referenced below should assist the IEAB in checking their assumptions and in developing ranges of mortality values to be considered in the model. Validation of parameter values also could be provided by fish tagging experts in the region. In some cases, Dr. Jaeger was able to validate model assumptions with regional Fish Tagging Forum experts. In other cases, he was not able to do so.

a. *Size of populations (average number of smolts) for each stock (hatchery and especially native) originating in each of the 64 subbasins.*
   The total annual releases of salmonids from hatcheries are available from the Regional Mark Processing Center (www.rmpc.org) and the Fish Passage Center (www.fpc.org). The RMIS database (maintained by PSMFC) has greater detail, including information about coded-wire-tags, than does the Fish Passage Center online database. It is not clear whether the release values in Table A1 are intended to include total hatchery releases, releases with CWT only, or tagged plus untagged releases associated with CWT fish (some untagged fish are linked to CWT releases). The values in Table A1 are too low if they are intended to be total releases. For example, in 2008, approximately 95 million Chinook, 23 million coho, 15 million steelhead, and 1.9 million sockeye were released into the Columbia Basin based on an earlier query of Fish Passage Center data. Age at release is important to this analysis because subyearlings typically have lower survival

than yearlings, and therefore lower potential tag recovery rate, so the table should also show releases of yearling versus subyearling fish.

The ISAB is not aware of estimates for total numbers of natural-origin smolts in the Columbia Basin, although it is conceivable that total smolts could be estimated from hydroacoustic counts at dams after subtracting upstream hatchery releases and adjusting for in-river mortality. Some smolt data at dams are available on the Fish Passage Center (FPC) website (www.fpc.org/smolt_home.html). A memo by Zabel (NOAA Fisheries) provides estimates of hatchery and wild smolts for 2012 in various regions of the basin and may be useful to future modeling efforts (see www.nwr.noaa.gov/publications/reference_documents/reference_documents.html). The NOAA might have additional years of data and should be contacted.

ISAB (2011-1, Table C.4.2) used approximate estimates of natural-origin adult salmonids and assumed smolt-to-adult survival rates to back-calculate natural-origin smolts, an approach similar to the IEAB approach. However, a key difference is that IEAB did not use a representative smolt survival rate for each species and age group. The IEAB analysis simply assumed 200 smolts per adult (0.5% SAR). The CSS (2012) report cited by IEAB is one source for SAR data. The Fish Passage Center website allows one to query the CSS SAR data by river zone and species. FPC staff could be requested to run queries that are too complex for website users to run online. As described on page 33 of the IEAB report, it appears that the 0.5% SAR may have been adjusted for each species using the CSS report, but it is not clear if this was applied to natural-origin smolts. A variety of sources indicate that natural-origin smolts have higher survival compared with hatchery fish (e.g., see CSS (2012) and reports in the Lower Snake River Compensation Plan: www.fws.gov/lsnakecomplan/Reports/LSRCPreports.html). Regardless, estimates of natural origin smolts are much less accurate than estimates of hatchery releases. CSS reports show numbers of natural-origin Chinook salmon receiving PIT tags in large rivers within the Snake River Basin.

b. *Mortality rates by river reach, dam passage.* CSS (2012) and the NOAA Science Center are good sources to check the assumptions with regard to juvenile and adult mortality rates by river reach and dam passage (PIT tag data analysis). The FPC web site may allow queries against the database. Also, section 2 of the draft 2013 Comprehensive Evaluation might have summary data that is worthwhile (www.salmonrecovery.gov/BiologicalOpinions/FCRPSBiOp/ProgressReports/2013ComprehensiveEvaluation.aspx)

c. *Ocean mortality rates by stock (Page 33: "Ocean survival has been calibrated to realistic values and to ensure return rates similar to those observed: 2.5% for Chinook and Coho, and 4% for sockeye and steelhead, based on data from the Comparative Survival Study (2012 Annual Report)."* The report should clarify if ocean survival is meant to be from estuary to estuary (i.e., excluding all in-river mortality). We would not expect ocean survival to be the same for both Chinook and coho because coho salmon have a much shorter ocean residence time than Chinook. Chinook survival will vary depending on smolt age and size at ocean entry (sub-yearling or yearling), run timing group (spring, summer, fall), or release location (upper basin, lower basin). Page 33 references CSS (2012), which is an excellent source for these data, but the value of 2.5% survival for Chinook seems high (see comment below about inclusion of mini-jacks and jacks when querying Chinook PIT data). Survival at sea is expected to vary among species, life history type, and year, and the ISAB recommends that species- and stock-specific survival rates be used if available. The IEAB should work with CSS modelers and others involved in estimating ocean survival rates for harvest management (e.g., Pacific Fishery Management Council, Pacific Salmon Commission) to validate, modify, and improve ocean mortality assumptions in the model. The ISAB also notes the recent work by Rechisky et al. (2013) and the commentary by Hilborn (2013), which suggest possibly different ocean survivals for certain stocks. As noted elsewhere, it is not crucial to get these exactly right given the limitations of the model.

d. *Mortality from tagging (Page 34).* The ISAB has previously recommended additional studies to better estimate tag loss and tag-induced mortality associated with PIT tags, especially how tag loss and mortality may vary from hatchery to hatchery, among species, and so forth. Knudsen et al. (2009) and related documents have information on the assumptions on page 34. These investigators reported that PIT tag loss averaged 2% at release and 18.4% among fish returning 6 months to 4 years after release. Estimated smolt-to-adult return survival (SARs) of PIT-tagged fish was 25% lower, on average, than that of non-PIT-tagged fish because of a combination of tag loss and reduced survival. After correcting for tag loss, the estimated PIT-tag-induced mortality was 10.4%, on average, but reached 33% for one brood year (Knudsen et al. 2009). In addition, CSS (2011, p. 161) reported the findings of two long-term studies in which SARs of untagged salmon were 19% or 38% higher (geometric means) than those developed from PIT tagged salmon.

   During the review of the Lower Snake River Compensation Program, Casinelli (IDFG; www.fws.gov/lsnakecomplan/Meetings/2010SpringChinookHatcheryReviewSymposium.html) reported 30.6% of Chinook salmon spending two years at sea had shed their PIT tag (n = 36 fish). Greater tag loss over time would be especially problematic, if this were a common occurrence among PIT-tagged fish. However, Knudsen et al. (2009) did not detect an increase in tag loss associated with age at maturation of spring Chinook. See Vander Haegen et al. (2005) for information on CWT effects on Chinook salmon.

   The FPC also has a technical memo dated 2011-18-09 concerning tagging effects of PIT tags. This memo said the effects of PIT-tagging were extensively studied and documented by NOAA scientists during development of PIT-tag technology in the late 1980s and 1990s. The NOAA studies raised concern about tag retention in adult female salmon that were mature and near spawning. The studies also showed some effects on fish growth related to the presence of PIT tags, although not consistently. NOAA concluded that any type of fish handling and tagging is likely to reduce survival compared to untagged fish, and they speculated that PIT-tagging could reduce survival to adulthood by 5-10 percent. These NOAA studies also recommended that tagged fish be held for a month or more after marking to reduce effects on post-tagging SARs, a recommendation which has been implemented by most Program studies using PIT tags. Accordingly, there is an established regional protocol for PIT-tagging fish, a PIT Tag Marking Procedures Manual, which was prepared by the regional PIT Tag Steering Committee in 1999.

While more detailed information is likely available from the CSS and other reports produced periodically (see above), it is not critical to get the information exactly right as the FT model is supposed to be a blueprint for the program over many years. It would be more useful to conduct the optimization over a range of scenarios (e.g., low, medium, and high marine survival rates), concentrating especially on scenarios when survival rates are much lower than normal to evaluate if sufficient tagging is still being done. Further comments are provided in our response to Q3 below. It would be interesting to know if other scenarios lead to different recommendations (for example, in years of low survival it is more important to do genetic stock identification [GSI] than CWT because most of the CWTs disappear). This information could help managers of the system make decisions about “in season” adjustments to the amount and type of sampling conducted.

Similarly, the sensitivity of the model outputs and conclusions or recommendations to changes in the parameter values would be informative. For example, what happens if each parameter is marginally changed, say +/- 20%? Does the allocation of tagging numbers or tagging types vary dramatically in a non-linear fashion? If so, it indicates that some robustness must be added to the system by deliberately tagging more fish than necessary to guard against normal yearly variation in these parameters. Or, managers can consider whether effort should be made in trying to improve or change the parameter values that they can control. For example, if the conclusions are sensitive to the mortality rate of barged smolts, should effort be deployed to mitigate the effect of barging?

2. *Are there simplifying assumptions in the model that, given its intended purpose, limit the model’s credibility? How might these assumptions be changed to be regarded as an improvement? For example: Some species (or sub-species, or runs or stocks) are “lumped” together (e.g., spring and summer Chinook), in part to keep from having the model become unwieldy, and in part because of data and resource limitations. Given the intended use of the model, does the way species have been identified seem reasonable? Are there distinctions between sub-species that we should consider separating?*

The report could be improved by explicitly listing the important simplifying assumptions and their rationale in a Table. The report has a written description of the life-cycle used in the model (Appendix A), but no model equations are presented. Did the IEAB consider the life-cycle model being produced by NOAA? How do fish transition from one life stage to another? How do fish “move” from one location to another? Figure A2 was useful but was not referred to in the text. Because each combination of release-recovery location has a separate equation for the expected number of recoveries, it is not feasible to list them all, but presenting a few equations would help readers to understand the assumptions being made.

Appendix A outlines the parameter values used and their source, but some assumptions are not explicitly stated. For example, in systems lacking smolt-production numbers, a value of 200 smolts/adult was used which “is consistent with a stable population and a 0.5% SAR,” but no reference was provided for these values. The out-migration survival and in-bound adult survival rates across and between dams are assumed to be equal for ALL species and are consistent with agency reporting, but an explicit reference to the source of these values would be useful. For example, are they taken from the recently updated FCRPS BiOp?

The rationale that 100 tagged recoveries is appropriate for a 10% coefficient of variation (CV) was sufficiently explained, but why choose a 10% CV and why is the target CV equal for all indicators? The target number of tagged recoveries may be suitable for cost-effectiveness studies, but for program effectiveness, some differentiation between “nice to know” and “must know” indicators is needed.

Table A6 shows the set of detection requirements for hatchery-origin spring Chinook. More discussion of this table would have been helpful to explain why some combinations were blank. Are the tables for other species exactly the same, and if not, what would be different? The rationale for the entries in Table A6 is also a bit circular – the set of locations in the FT model where at least 100 detections were needed was defined as one in which the 10-year average was already 100 or more detections. Perhaps there are some release-recovery locations where too few detections are currently being made and more effort is needed to raise detections in these release-recovery locations. This is especially true for ESA stocks which may be currently too depressed to enter as a constraint for detections in the FT model. Because Table A6 is key to the optimization of the model, the ISAB recommends that a more careful review be made of the table to ensure that no entries have been missed or included that are unnecessary and that the detection requirements more closely reflect the priority accorded to each indicator.

Calibration was only mentioned once (p. 33) in which it is stated that ocean survival rates were calibrated to realistic values. Additional discussion of this topic is required on all parameters that required calibration and why other parameters were not calibrated. For example, because a SAR reflects survival during both juvenile out-migration and ocean life, many combinations of the two parameters will give the same SAR. How sensitive are the results of the model to changes in the balance of juvenile and ocean survival with the same SAR?

Is it appropriate to assume that data management costs are the same for all of the tagging approaches? The authors could provide more rationale behind this assumption. Data management costs may be fixed costs, but there are substantial costs related to data archiving (e.g., archiving genetic samples is much more costly than archiving a CWT).

What is the rationale behind assuming that hatchery releases represented 99% of the average number of fish released? The report indicates that it is based on CWT data and PIT-tag data, but can this be clarified a little more?

One of the limitations of the model is that each indicator requires a specific number of recoveries/detections for each type of tag; for example, a minimum of 100 tag recoveries/detections are needed to estimate survival rate for juveniles from spawning grounds to Bonneville Dam. But there are cases where combinations of two different tagging methods can provide information on two performance measures where the pair of data sources would be insufficient if considered on their own. For example, indicator stocks (with CWTs) can be used to represent an aggregate of several different stocks in a similar geographic area under the assumption that fishing effort and ocean survival of the aggregate of stocks will match that of the indicator stock. A GSI on the ocean fishery provides information on the proportion of the aggregate (and the indicator) in the mixed fishery but not on abundance. CWT returns from the mixed ocean fishery can only estimate the product of the proportion of the aggregate x proportion of aggregate which is tagged in the ocean fishery. Finally, sampling of the indicator stock in the terminal run provides information on what fraction of the indicator stock had a CWT. Together, the three sources of information allow estimation of the return of the total aggregate, which is not possible using any of the individual components alone.

It is not clear in the FT model how to optimize the effort to get the best information. For example, adding more genetic sampling increases information about one parameter, but it is not obvious how this impacts sampling efforts for the other life-stages. These types of models are often estimated using Bayesian methods where the flow of information from data to estimates is not always clearly delineated. The use of these types of models to extract as much information from multiple sources as possible is becoming increasingly more common.

Can the IEAB model be optimized so that, for example, a triplet of indicators must be satisfied in different ways? For example, by estimating the aggregate return requires xxx GSI, yyy CWT returns in the fishery, and www CWT returns from the terminal area?

It is not clear what happens in the FT model if some sources of information become unavailable. For example, suppose that a fishery is terminated because of conservation issues and CWT are no longer available. How will the model show that information from this fishery must be recovered elsewhere?

3. *Are there other simplifying assumptions we have made that are of particular concern for representing the fisheries – keeping in mind the intended purpose of the model? (E.g., the model is deterministic rather than stochastic, and so ignores how the year-to-year variation in survival and productivity affects fish tagging costs and outcomes). How might these assumptions be changed, or what sensitivity analysis might be appropriate?*

Survival of salmon from tagging and release to recovery is a key metric influencing the cost of recovering a specific number of tags. Since the model is only intended to examine “steady-state” situations, ignoring the year-to-year variation is appropriate. However, current fish tagging rates are determined in part by the need to meet tag recovery needs when survival is low. Consequently, several different scenarios should be run (e.g., poor, average, and good river- and ocean-survival, good and poor smolt production) to see if the recommendations on allocation of effort are very different. As noted above, it may be possible for managers to adjust sampling “in season” to compensate for poor data elsewhere.

Species and run timing groups have different survival rates and different vulnerabilities to ocean fisheries largely due to different migration patterns (see Weitkamp 2009, Rechisky et al. 2013). The location of tagging may be another important variable if SAR, for example, declines from the lower to upper Columbia basin. Subyearlings and yearlings have different survival rates. Again, sensitivity analyses might be employed to evaluate tradeoffs in tagging related to lumping versus more discrete use of species, race, and location. For example, presumably splitting a stock into two components would double the tagging required to meet the minimum of 100 detections in the indicators. Are there related stocks that, when combined, reduce the amount of tagging required?

The model’s sensitivity with respect to costs also should be investigated. For example, in an average year, what would happen if genetic sampling costs were halved? Is there a tipping point for costs at which the recommended type of tagging would change? This is especially true for genetic sampling because costs will likely decline over time and technological improvements can drastically change the price of genetic analyses.

Similarly, the model should be run under scenarios where a particular set of information is no longer available, as noted earlier. What happens, for example, if a terminal harvest of some stock is closed due to conservation concerns and no CWT returns are available? In such a case, do other requirements go up dramatically because sampling needs to be done much earlier in a life cycle when fish are harder to track? Does the model indicate these ripple effects? This concern relates to our earlier comments about parameter estimates coming from sharing information across multiple sources.

The current model also treats each brood year of a species independently of other brood years and each stock independently of other stocks. Given the structure of the model, this is appropriate. It is unclear whether species were modeled differently. The tables show different results among species, but do those differences merely reflect the numbers of fish put into the model or were some life stages or survival rates represented differently among species?

The description of the PIT-tag analysis should be clear about whether or not jacks and mini-jacks, both of which are mature salmon, were excluded, and if so, why. For example, Larsen et al. (2013) estimated that 68% of all maturing fall Chinook produced from yearling releases in the basin were mini-jacks and jacks (mini-jacks mature as yearlings and do not emigrate to sea; they can represent up to ~50% of male salmon released from hatcheries). Only 32% of the return during 2002-2009 were so-called adult salmon (ocean age-2 and older). Inclusion of mini-jacks (and jacks) can have a significant effect on SARs according to Larsen (in this example, 2.5% versus 0.5%).

4. *The model minimizes the cost of generating "indicators" or metrics for monitoring and research purposes. These indicator requirements include attaining a desired level of statistical confidence for reach survival, SARs, exploitation rates, etc. One difficulty in specifying the model has been establishing the necessary detection and recovery rates that correspond to the necessary or desired confidence bounds. In our model we used 100 detections as the basis for coefficient of variation of 10% (see the appendix C in the report). However, some guidance is needed on the relationship between detection/recovery requirements and the necessary or sufficient levels of precision (should they be the same for all indicators? Do they need to be achieved annually (i.e., every year versus every two years)?). For harvest recoveries in particular, we had difficulty translating management questions into specific detection/recovery requirements to introduce as constraints in the model. How might the model representation of tagging for harvest management questions be improved?*

Precision requirements for indicators are difficult to evaluate because of the wide diversity of uses for the information. Such an evaluation would require a high level assessment of which information is most valuable and which can change depending on environmental conditions and other factors. For example, if PIT-tag studies showed a poor year for smolt survival to Bonneville, then information on ocean survival becomes relatively more important to prepare for potential disasters when the fish return. An extreme disturbance event on a tributary affecting an ESA-listed population would increase the value of good information on subsequent smolt emigration from that population. Rather than trying to weight all indicators, it would be more fruitful to look at scenarios (e.g., a poor year for smolts to see which indicators can predict if problems will arise later in the life cycle).

The Pacific Salmon Commission's Expert Panel on the Future of the CWT program for Pacific Salmon (2005) was faced with a similar problem and stated that: "The utility of a decision-theoretic approach, integrating costs, benefits, and risk into a formal evaluation structure should be investigated as a means of prioritizing potential improvements (e.g., measures to improve CWT data reporting, sampling designs, and protocols) to the CWT system. The approach should identify the release group sizes and recovery programs required to meet the statistical criteria for CWT recovery data. Sampling programs should include all fisheries, hatcheries, and spawning ground areas where CWT exploitation rate indicator stocks are present." Similar comments apply here and are related to previous comments about changes to measure program effectiveness.

The minimal detection requirements at harvest are the most difficult to assess because of the "indirect sharing" of information from harvest data across other indicators, as exemplified earlier. Nandor et al. (2010) note that stock contribution studies require far more CWT fish to generate meaningful recovery rates on a regional basis than stock assessment studies. Stock contributions in a region are assessed over time, and this time requirement would further increase the need for greater sample size. According to Nandor et al. (2010), who reviewed the Expert Panel Tag report, “The Columbia River Hatchery Reform Project also identified the need for increased tagging levels to better evaluate the success of hatchery rearing programs in the Columbia River Basin (Hatchery Scientific Review Group, 2009). Additionally, coded wire tagging and subsequent fishery sampling efforts have been reduced due to budget constraints (ISRP/ISAB 2009-1).”

Sometimes, tagging provides information on issues not anticipated, such as measuring avian predation. Unless indicators are identified and provided, the current FT model cannot incorporate the benefit of this unintended benefit in the model. The ISAB recognizes that not every potential opportunistic use of tagging data can be anticipated, but brainstorming with fishery managers may provide some guidance on future needs. For example, the recently funded acoustic tagging of adult fall Chinook salmon in the Snake River by Nez Perce/WDFW depends upon accurate stock identification of the tagged fish, which is determined from PIT tags inserted during the juvenile stage.

5. *How could the IEAB's economic programming model for fish tags a) be used as a decision support tool in the basin and/or b) serve a valuable role in promoting future improvements in fish tagging cost and program effectiveness?*

The current FT model only has a limited role in evaluating program effectiveness before the program-wide, minimal information needs are articulated. The FT model shows how to deploy tags in a most cost-effective method for the current tagging and detection system. However, the model does not indicate if the current system is sufficient.

Within the currently configured system, a sensitivity analysis of parameters in the FT model could be useful for determining which parameters are key in driving the cost allocations. This would help to evaluate trade-offs or prioritize efforts to improve parameter estimates for certain life-stages, to improve detection rates, or to change tagging rates. It might also help to discern what life stages are key for assessment (e.g., where to focus tagging or detection efforts).

The FT model is also useful for long-term planning to investigate the impacts of losing components (e.g., it is no longer possible to harvest in certain fisheries) and of long-term technological change (e.g., full parental genotyping), again assuming that the current system is what is needed.

Finally, the model can also be used “in-season” to see how other parts of the program may need to change in response to, for example, a lower-than-expected survival of out-migrating juveniles.

6. *How could the model be improved or refined to better benefit tagging-related management decision making?*

It is difficult for the ISAB to respond to this question because information provided by tagging programs is needed for many different purposes. For example, estimating the incremental cost of tag detections of specific stocks in specific ocean fisheries is interesting but does not by itself address management needs. It may be inexpensive to increase the recovery of a specific stock by one fish, but this stock might have little or no influence on fishery management in the area. Conversely, it may be expensive to increase the recovery of a tag from an ESA-listed stock, but the additional information is very valuable. Again, a prioritization of information needs is needed. For example, can the model provide information on what cost-saving may be achieved by changing the way fish are tagged or where tags are recovered? If fish with CWT all had fin-clips and fish without CWT were not clipped, would this reduce the costs of inspections, and vice-versa? If fin-clipping was no longer used, would this increase the costs and shift recommendations to other tag types? Can streaming all fish recoveries through a single location reduce costs?

The people and agencies relying on information provided by CWT and PIT tags and genetic composition need to be consulted about their use of tagging data in management decision-making. Some of this usage depends on various scenarios for river and ocean survival. For example, in the case of years with poor smolt production and poor river survival, information on ocean survival (i.e., CWT returns from fisheries) becomes much more important. A crude loss-function could be assigned for each recovery-location based on the number of tags returned and the model could then be optimized to maximize information. Further, a hierarchy of information needs (e.g., ranging from “critical” to “nice to have”) could be added to the model with critical constraints always satisfied but “nice to have” constraints having some leeway in being satisfied.

7. *How could this model help the region better understand the most efficient deployment of PIT tags, as the use of PIT tags is growing and there may be inefficiencies in the use of PIT tags in the Basin?*

The current FT model may need revision to account for unexpected uses of PIT tags. For example, the ISRP recently reviewed a proposal by the Nez Perce Tribe and WDFW involving the straying of fall Chinook salmon in the Snake River basin where overall proportion of hatchery origin (pHOS) is estimated to be approximately 70%. This proposal opportunistically relied upon adult PIT-tagged fish returning to the dams for subsequent tagging with radio tags to further evaluate the behavior and locations of straying salmon. The investigators noted that the number of PIT-tagged Chinook salmon was likely to decline in later years of the multi-year investigation because PIT-tagging rates have declined. This use of PIT tags is currently excluded from the FT model.

The current model also does not account for information sharing across different stocks. For example, is it really necessary to have the same specified number of PIT-tag recoveries from each stock that migrates past a common set of dams? Perhaps fewer recoveries from each stock can be obtained and information shared across stocks with similar life histories? Estimates of survival computed separately for each stock using only data for that stock might be relatively poor, but estimates computed by sharing information over several stocks might actually be quite good. The question of splitting or pooling stocks to provide common information (e.g., common out-migration survival rates) was not considered in this model and should be addressed, especially for some of the smaller tag groups.

Can the model be used to identify studies that currently are tagging fish but could eliminate or reduce their tagging activities and still meet their data needs by using fish tagged by other projects? These studies could be called “free riders.” Presumably, these studies would be “marginal free riders.” That is, if their tagging effort was reduced, it would not jeopardize other studies.

8. *How could this model help the region recognize the potential comparative advantage between CWT and genetics for harvest data collection and/or other types of information?*

Model results indicate that CWT costs overall are about half the costs of genetics. This is primarily due to estimated lab costs of genetics ($40 per fish) versus CWT ($5 per fish) in the model, and the model requirement for lab processing of a larger number of genetic samples than CWT samples. These results likely provide sufficient information for comparing the potential advantage between CWT and genetics for harvest data collection at present. Nevertheless, the estimated cost of $40 per fish for detecting genetic markers seems high, and might be substantially reduced if work was routinely contracted to a commercial lab through a competitive bidding process. Newer screen techniques also may quickly reduce costs. Similarly, costs for CWT recovery seem low given the de-sequestering of the adipose clip for mark-selective fisheries and release of fish that are coded-wire tagged but not marked with an adipose clip by some agencies. The sensitivity analyses recommended above should explore a range of GSI and CWT costs.

One of the difficulties with evaluating the usefulness of genetic sampling is that genetic sampling, on its own, may not provide all of the information necessary for management. However, a small amount of genetic sampling, when combined with the standard CWT programs, can lead to great efficiencies and provide information not accessible except through a massive CWT program (see the previous example). If genetic sampling programs are to be expanded, some review of the current systems is needed to evaluate how genetic sampling can be used most effectively. Similarly, full-parental genotyping complemented by a small amount of CWT again leads to great efficiencies in estimating returns in a mixed aggregate of fish stocks. The current IEAB FT model has difficulty handling requirements for a combination of tag types because of its structure.

The IEAB report also does not consider thermal marking of otoliths. Thermal marking can be a very cost effective tool for mass marking salmon. Similar to the previous comment, CWT, thermal marking, and genetic stock identification could be strategically combined to maximize program effectiveness and cost-effectiveness. Unique marks or patterns can be made on 100% of salmon otoliths in a raceway simply by altering water temperature. Marking requires relatively low costs after the initial investment to install a chilling system (see below). Many otolith patterns can be developed, and the controlled use of patterns is organized annually at meetings held by the North Pacific Anadromous Fish Commission. Approximately 27-30 million hatchery salmon (Chinook and chum) receive thermal marks in the Columbia River Basin each year (S. Schroder, ISRP, pers. communication). In Southeast Alaska and Prince William Sound essentially 100% (>600 million juvenile salmon) receive thermal marks each year. However, the detection and reading of thermal marks requires sacrifice of the fish.

There are two costs associated with thermal marking (S. Schroder, ISRP, pers. communication). These are the capital cost of a water chilling system and the operating cost. In-line water chilling systems that can deliver 100 to 150 gallons of water chilled 3 to 4°C below ambient temperature cost $75,000 to $100,000 per hatchery. Such systems typically last 20 to 30 years and can be used not only for thermal marking but for other fish cultural purposes as well. For example, it is common for hatcheries to delay development in early egg takes by chilling incubation water so that fish can be ponded at approximately the same time even though the parent fish where spawned on different dates. Operational costs for these systems are probably about $3,000-$5,000 per month for electricity and some additional costs for yearly maintenance, probably less than $1,000 per year. Thermal marks can be applied to every fish produced from a hatchery, so potentially 20 million or more fish per year in a hatchery could be marked for only ~$7,000-$9,000 of electricity; adding in the cost of the chilling system that would bring the cost up $15,000 per year. The cost of decoding otoliths varies by species and life stage. Current costs for WDFW are $13.75/fish for Chinook; and $11.00/fish for chum, sockeye, coho, and pink salmon. Costs are less expensive if smolts or fry are being examined.

Additional Comments

Executive Summary: The Executive Summary was informative, but the “rationalization” and “fair share” bullets need some revision. The rationalization bullet point indicates that one goal of rationalization is “to maximize program effectiveness,” but program effectiveness was not considered in the IEAB report. Similarly, the summary discussion of the term “fair share” is generic, but the report does not delve into issues of “fair share” because of the difficulties in assigning values. Are these more generic recommendations rather than a finding of this report?

In Section III, the opening statement indicates that three topics – cost-effectiveness, program effectiveness and fair share – will be addressed, but the latter is not covered in this section.

Page 11, item (i). It is not clear what “tables” the authors were referring to. Is Table 3 an example of such a table? Presumably, the argument that when the marginal cost to increase the number of detections past the minimum number is 0, this indicates that there are more than enough recoveries (i.e., more than 100) and so there is no "additional" cost to get at least 100 recoveries. This point is never explicitly stated in the paper.

Page 12. From the discussion of harvest results on page 12, it is not clear if the FT model included possible mortalities due to handling. The appendix sets tagging mortality at 10%. The authors do mention tagging mortalities for CWT and PIT tags on p. 34, but no rationale is provided for these rates. Are these numbers based on any specific studies or general assumptions commonly made? Do these mortalities due to handling vary among species and life stages?

Page 16. The discussion of "fair share" addressed what type of evaluation is provided and not provided by the FT model, but it is unclear what the ultimate conclusion was. Do the authors conclude that the model cannot address "fair share" or that "fair share" is a concept that cannot be achieved in the Columbia River Basin?

Table 1. Is it appropriate to include dates over which these data on the observed number of PIT-tags are averaged? Units are also required (even if number of fish) to keep the table clear. Why are there no lines in the table for the Lower Columbia River? More explanation should be added to the caption to make the table more useful and easier to interpret.

Table 3 does not seem to be referenced in the text.

Page 33. The discussion about ocean migration and fishery exploitation is unclear. Table A5 contains data from a source that seems worth citing in the text here. The methodology described is very vague and needs to be clarified.

Page 34. The discussion about transportation describes the implementation in the FT model, but how realistic is this description? Is this very similar to what happens in reality?

Page 34. The use of endogenous and exogenous, while in common use for economic models, seems confusing here. An explanation of these terms would make these paragraphs easier to follow.

Page 37. Nandor et al. (2010) stated that approximately 275,000 CWT are recovered each year (coastwide) at a total cost of $12-13 million, or approximately $45 per recovered tag. Cost to inject a CWT into each fish is approximately $0.15-0.20, and total tagging costs exceed $9 million per year. In 2004, ADF&G estimated that their cost to sample fish for CWTs was $20 per tag, and their cost to dissect the tag from the fish, decode the tag and make the data available was $18 per fish. Thus, approximately $38 was spent to recover each fish. How do these costs mesh with those assumed in the FT model?

Captions for the tables need to be more descriptive and to clearly distinguish whether the data presented are model results, background data for the model, or input data for the model.

Figures A1, A2; Tables A1, A2. These were not referred to in the Appendix or the text. Figures A1 and A2 could be referred to, and included, in the main text. Also the tables that were referenced in the text of Appendix A were referred to out of order.

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