Evaluation and improvement of the Survey Method used to estimate Chinook escapement along the West Coast of Vancouver Island (WCVI)

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Diana McHugh and Diana Dobson

Stock Assessment Division

Department of Fisheries and Oceans Canada

3225 Stephenson Point Road

Nanaimo, BC

V9T 1K3

ABSTRACT

This project collected additional information from spawning populations of Chinook on the WCVI in order to test assumptions of the current area-under-the curve (AUC) escapement estimation model and improve the overall assessment framework building on the work conducted in 2010. In 2011, three study populations were tagged with radio and external spaghetti tags, a reduction from the four study populations in 2010. Tagging allowed direct estimation of survey life and observer efficiency, two parameters assigned qualitative values in the current AUC model used to estimate Chinook escapement. River discharge and visibility data were collected to examine the relationship between survey conditions and observer efficiency. Tag information was used to generate independent estimates of escapement through mark-resight models. In addition, a maximum likelihood method was used to estimate escapement as an alternative model to AUC estimation.

With a few exceptions, results indicate that survey life estimates are generally about levels that have been assumed and similar to those measured in previous studies. Observer efficiency is typically lower than the qualitative estimates reported by crews that have been used in AUC estimates. Much of the variation in observation efficiency was explained by river conditions (horizontal visibility and rate of discharge). When the AUC models were corrected for measured observer efficiency and survey life, escapement estimates were similar to those generated through either mark-resight or maximum likelihood models. The qualitative uncorrected AUC estimates were roughly 20% lower than the quantitative AUC estimate, but comparable to the both the likelihood and mark-resight models. Still, after adjusting escapement estimates and accounting for uncertainty, populations of wild WCVI Chinook systems are below provisional escapement targets based on S_{MSY} levels. This observation is consistent with the current status of assessment of WCVI wild Chinook.

This project is on-going and results from the 2012 study will further inform the analysis, conclusions and improvement of the WCVI Chinook escapement estimation and the overall assessment framework. Two separate reports details the maximum likelihood model for escapement estimation that was developed and modeling work to explore the optimization of the overall WCVI survey framework.

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1.0 INTRODUCTION

WCVI Chinook stocks are important relative to the coast-wide Chinook resource. They contribute a significant amount of production to Aggregate Abundance Based Management (AABM) fisheries in Alaska south to Vancouver Island. The total known number of WCVI Chinook populations is about 101, based on various records.

WCVI Chinook populations remain at low levels. Populations originating from Clayoquot or Kyuquot Sound are of particular concern. Although the spawning habitat is relatively pristine in these areas, the populations have not responded to management actions (in fisheries) and remain at poor status. For a more detailed description of how WCVI Chinook and this project fit into the Southern Endowment Fund mandate, please refer to the 2010 Final Report for this project.

Currently, escapements to approximately 18 systems throughout the WCVI are surveyed and sampled annually by DFO-contracted and First Nation crews. The time series of escapement estimates are shown in Table 1. Together, these systems account for about 70% of the WCVI Chinook production outside major enhancement facilities, based on the historical record. With the exception of the populations in Area 24 (Bedwell, Moyeha and Megin) and Area 26 (Artlish, Tahsish and Kaouk), most have been enhanced, either through fry out-plants from the major facilities or through smaller-scale community enhancement facilities.

Escapement to these systems is estimated using the area-under-the-curve (AUC) method (English et al. 1992). Crews count spawners on the systems several times over the duration of the run (i.e. typically through 5 to 8 surveys, although less in recent years with budgetary restrictions). Chinook are usually counted during swims, but other methods may be used, such as aerial surveys or bank walks. Spawners are sampled for age at return (scales) and origin (through otolith mark rates) if enhancement has occurred. Surveys are scheduled for every 7-10 days during September, October and November, for a minimum of 4 surveys per system not including surveys for zero counts. Weather, water conditions, and water flows may impact this schedule. Generally 1 to 3 observers per team start surveys from upstream migration barriers, or the observed upstream limit, and snorkel downstream to the tidal limit.

Although survey methods have been consistently applied since 1995, the AUC method that has been applied does not allow for the description of statistical uncertainty in the population estimates. Two key parameters in the estimation, observer efficiency and survey life vary among surveys, years and populations. Because these have not been measured for every year and system (i.e. they have, for the most part, been assumed constant within and among systems), the AUC estimates potentially represent an index of escapement as opposed to an estimate of total escapement. Moreover, there is some concern that the methodology produces biased results (i.e. biased low). These issues have resulted in contention around the accuracy of spawner counts for WCVI Chinook, which in turn has presented challenges for evaluating the performance harvest management strategies developed under the Pacific Salmon Treaty (PST). Doubt regarding their accuracy, also presents challenges for using these data for developing escapement targets that may, in turn, be used to trigger further fisheries reductions under the PST. Therefore, there is a need to quantify the uncertainty of WCVI escapement estimates and better understand the potential bias of the estimates.

There are two components of this project. This first component is a field study with the objective to further work completed by Trouton et al. (2007) and previous unpublished studies that examined survey life and observer efficiency for WCVI Chinook populations. For the field study, a further objective was to apply Korman et al.'s (2007) methodology to examine the use of environmental correlates to estimate observer efficiency (i.e. in lieu of implementing costly field studies every year). The second component of the project is to conduct modeling work to inform developing a robust statistical framework that can be used to quantify the uncertainty of WCVI escapement estimates, standardize the methodology used for escapement estimation and inform the survey design and allocation of resources. The modeling component was completed in 2010 (Labelle). The work of comparing historical abundance estimates to the estimates generated by the new model is still on-going.

The specific objectives of the field study are to:

- Estimate total escapement of adult Chinook through a mark-resight study on selected systems;
- Quantify Chinook survey life and observer efficiency for selected systems;
- Determine potential environmental correlates with observer efficiency;
- Compare the mark-resight, maximum likelihood (constructed by Labelle in 2010), qualitative AUC (assumed survey life and observer efficiencies) and quantitative AUC (measured survey life and observer efficiencies) escapement estimates.

The specific objectives of the maximum likelihood model development were to:

- Identify and use scientifically defensible procedures to provide AUC escapement estimates and associate levels of uncertainty for selected WCVI systems surveyed recently.
- Based on the results obtained, assess the relative merits of alternative survey procedures that can be used to estimate total escapement to selected WCVI conservation units (CUs).
- Determine the relative benefits of complementary surveys to be initiated shortly in terms of gains in accuracy and precision of future AUC escapement estimates for selected CUs.

Using results of this study, our intent is to establish a robust statistical framework, tools and tested field methodology to continue to describe the statistical uncertainty of WCVI escapement estimates after this project is terminated. It is also our intent, to gather the requisite information to establish escapement goals for WCVI Chinook populations.

2.0 METHODS

This report generally describes methods and results from the Field Study component of the project. A more thorough description is available in the 2010 Final Report of this project (Dobson, 2011). These methods focus on changes to the methods between 2010 and 2011.

2.1 STUDY SYSTEMS

There were three study systems including the Marble, Leiner and Tranquil Rivers. All of the study systems are part of the extended PSC indicators for WCVI Chinook. The study systems are typical of most WCVI Chinook bearing rivers; topography is steep and spawning is generally constrained to the mainstem. Similar to the WCVI area as a whole, these rivers are located in areas subject to high levels of precipitation during spawning periods.

The Marble River is located in Quatsino Sound and flows into Holberg Inlet (DFO Statistical Area 27). The spawning length is 4.9 km from upstream migration barrier to the mid tide area. Total watershed area is relatively large at 194 km^2. Survey conditions in the Marble are challenging; frequent flood events reduce visibility and recovery time after flood events can be prolonged due to two relatively large lakes above the spawning barrier. The system has relatively good road access. Since 1995, escapement estimates for Chinook have averaged about 2900 (Table 1). The estimated habitat based escapement target is about 1200 (Table 2). There has been some modest and periodic stock enhancement by a local stewardship group.

The Leiner River is located in Nootka Sound flowing into the head of Tahsis Inlet (DFO Statistical Area 25). The spawning length is 1.9 km from the upstream migration barrier to the mid tide area. Total watershed area is moderate at only 104 km^2. Survey conditions in the Leiner are usually favorable with clear visibility and quick recovery times after flood events. The system has relatively good road access. Since 1995, escapement estimates for Chinook have averaged about 460 (Table 1). The estimated habitat based escapement target is about 680 (Table 2). There has been some modest stock enhancement by a local stewardship group.

Tranquil creek is located in the south end of Clayoquot sound flowing into the head of Tranquil Inlet (DFO Statistical Area 24). The spawning length is 3.5 km from the impassable falls to the mid tide area. Total watershed area is relatively small at only 60 km^2. Survey conditions in the Tranquil are usually favorable with clear visibility and quick recovery times after flood events. The system has relatively good road access. Since 1995, escapement estimates for Chinook have averaged about 750, but have not exceeded 250 in the last five years (Table 1). The estimated habitat based escapement target is about 420 (Table 2). There has been some modest and periodic stock enhancement by a local stewardship group.

2.2 FIELD STUDY

For all systems, crews were instructed to conduct up to five tagging events through beach seining or angling. Due to problems seeing the “Kurl-loc” tags in 2010, only spaghetti tags plus a secondary mark, operculum punch, were applied, for mark-resight estimation and development of tag depletion curves. In addition, they were instructed to apply up to 30 radio tags. The radio tags used for this project were coded motion tags (SR-M16-25) which emit a different signal when the fish stops moving for more than 24 hrs. Those fish with radio tags applied had a corresponding external tag applied.

For each system, crews conducted up to 12 snorkel surveys recording observations of marked and unmarked Chinook in each 500m section of each stream. Surveys were planned from late August to mid-November. Survey crews examined carcasses throughout the swim surveys to estimate visual tag loss and collect biological samples. Before each swim survey the following data were collected: horizontal distance of visibility under water (each swimmer), water temperature, water flow, gauge height and pool secchi depth.

2.2.1 Changes in 2011

To reduce tagging stress, data collected during tagging was reduced to tag number, color, and condition, so length and sex are only available from carcasses or individuals taken for broodstock.

Fixed telemetry receivers were not installed at Marble Lake due to flooding problems in 2010. Instead, surveys of Link and Benson Rivers above the Marble were conducted to determine whether significant numbers of fish were spawning above the index section. Telemetry surveys were coordinated in conjunction snorkel surveys to locate radio tagged fish and estimate emigration tag loss (straying) as well as observer efficiency. In the Marble, telemetry surveys continued while high water precluded snorkel surveys to allow for an estimate of survey life based on observing how long individual tags remained alive in the index section.

2.3 ANALYSIS

2.3.1 Tag Loss

Tag loss is calculated by dividing the total number of carcasses with a secondary mark (operculum punch) by the total marked carcasses recovered for each system.

2.3.2 Survey Life Estimation

Survey life is defined as the mean duration of time (days) that individuals of one species were available for counting in the stream or the mean number of days fish were alive in the stream (Perrin and Irvine 1990).

The average survey life for the study systems was estimated through tag depletion curve of the radio tags on the Marble, Leiner, and Tranquil rivers. The length of time each tag was active in the area provided an estimate of the survey life of individual Chinook as well. The radio tags used for this project were coded motion tags (SR-M16-25) which emit a different signal when the fish stops moving for more than 24 hrs.

A third survey life estimate was estimated through the depletion curve based on re-sighting the external tags. The area-under-the-tag-curve (AUC_{tag}) survey life was determined by tagging salmon in the lower portion of the stream, prior to the onset of spawning and resighting the tags during swim surveys. Swim survey counts of tagged fish were not corrected for tag retention due to low sample sizes and resultant poor precisions of tag loss rates. Further, counts were not corrected for observer efficiency (assumed 100%). Swim counts were used to generate the trapezoidal approximation of the AUC_{tag} and the total tag days were divided by the original number of tags applied to estimate survey life in days as described by Irvine et al (1992) and Hetrick and Nemeth (2003).

2.3.3 Observer Efficiency Estimation

Observer efficiency was calculated from the proportion of the visually and radio tagged fish seen by the swimmers versus the total number available as determined by telemetry surveys conducted prior to spawner surveys.

2.3.4 Observer Efficiency Correlates

The relationship between observer efficiency and the ratio of horizontal visibility and discharge was explored through the method described by Korman et al. (2002). Data collected directly from the Marble, Leiner, and Tranquil rivers were analyzed.

2.3.5 Escapement Estimation

Comparisons of escapement estimates generated through the following methods were made (when data for the system were sufficient to support the particular analysis):

- The trapezoidal AUC method with qualitative assessment of observer efficiency and survey life (i.e. the method normally used to generate WCVI escapement estimates);
- The trapezoidal AUC method with quantitative assessment of observer efficiency and survey life based on 2011 study results;
- The mark-resight method using the joint hypergeometric maximum-likelihood estimator (JHE) described by White (1996);
- The mark-recapture method using the Chapman modification of the Petersen estimator (Ricker, 1975 and Cousens et al., 1982)
- The unimodal maximum likelihood escapement estimation model developed by Labelle (2011) as part of this project;
- the biomodal maximum likelihood escapement estimation model developed by Labelle (2011) as part of this project.

For context, the results were compared to the provisional habitat based escapement targets that are estimated for the study systems using the Parken et al. (2006) methodology.

2.3.5.1 Trapezoidal Approximation

Total live Chinook salmon counts were plotted for each date to form the fish curve, and the areas of the trapezoids were summed to estimate total fish-day component of the AUC. The total fish-days or the AUC ($\hat{A}_i$) for year i was (Irvine et al. 1992):

$$\hat{A}_i = 0.5 \bullet \sum_{j=2}^{n} \left(t_j - t_{j-1}\right) \bullet \left(\hat{p}_j + \hat{p}_{j-1}\right),$$

where t_j was the number of days since the first fish commenced spawning, n – 2 was the number of swim surveys, and $\hat{p}_j$ was the number of salmon counted on day j (sum of the fish counts by strata). For the qualitative AUC, the observer efficiency used was the self-reported value from the survey crew. The quantitative AUC used the proportion of radio tags present that were observed as the observer efficiency if available or 100% if radio tags were not available. Surveys were temporally bounded by the day the first fish commenced spawning (j = 1, $\hat{p}_j$ = 0) and the first day when there were no longer any live spawners (tn, $\hat{p}_n$ = 0). The first and last dates of spawning were estimated from spawning observations made during swim surveys. Note that t_j = 1 and p_j = 0 for the day when the first fish commenced spawning and t_n was the number of days that live spawners were present; thus p_n = 0.

The AUC method for calculating the annual escapement ($\hat{N}_{i,AUC}$) was

$$\hat{N}_{i,AUC} = \frac{\hat{A}_i}{\hat{S}_i},$$

where $\hat{S}_i$ was the survey life in year i defined as the mean length of time (d) live fish were available for counting. Both the area-under-the-tag-curve and index survey life were used to determine escapement estimates using the AUC method.

2.3.5.2 Carcass Mark-Recapture

The adult Chinook salmon population ($\hat{N}$) using carcass recoveries was estimated using the Chapman modification of the Petersen estimator (Ricker, 1975 and Cousens et al., 1982):

$$\hat{N}_{i,MR} = \frac{(M+1)(C+1)}{(R+1)}$$

where N is the estimate of adult salmon, M is the number of adult salmon marked, C is the total number of adult carcasses examined for marks and R is the number of marked adult carcasses recovered (Ricker, 1975). This adjusted Petersen estimate is the most commonly used mark-recapture formula and provides a nearly unbiased estimate of N (Cousens et al., 1982).

2.3.5.3 Mark-Resight

The visual swim survey re-sight procedure involved counting the number of marked and unmarked Chinook salmon; whereas, the AUC estimates utilized total live counts. Total escapement was calculated using the joint hypergeometric maximum-likelihood estimator (JHE) described by White (1996):

$$L(N \mid M, c_k, r_k) = \prod_{i=1}^{k} \frac{\binom{M}{r_k}\binom{N-M}{c_i - r_k}}{\binom{N}{c_k}},$$

where $L(N \mid M, c_k, r_k)$ = Likelihood of N conditional on the observed values of M, c_k, and r_k, and N is the population size, M is the number of tagged fish in the study area (tags applied), c_k is the number of fish inspected for tags on the kth survey, and r_k is the number of tagged fish counted on the kth survey. The likelihood of different escapements and confidence bounds around the estimates were calculated using the likelihood profile.

Tag loss, which was assumed to occur during competitive interactions among fish actively spawning, was not used to adjust mark-resight observations as sample sizes were too low to detect tag loss over time or to provide a precise estimate of tag loss.

2.3.5.4 Maximum Likelihood Model

This method assumes an underlying statistical distribution model of fish arrival and death from which the number of fish alive in the stream can be predicted on a given day, and the pattern of arrival and death is assumed normally- or beta-distributed (Hilborn et al.1999). Observer counts of fish and index survey life are used to estimate the number of fish in the stream. For this project, Hilborn's (1999) likelihood model was modified to allow for uncertainty in the survey life and observer efficiency and also for bimodal migration patterns (Labelle 2011, see 2010 companion report).

3.0 RESULTS AND ANALYSIS

3.1 FIELD STUDY

Survey conditions in 2011 were not ideal. Flooding resulting from higher than average precipitation caused accessibility issues both in terms of road access and river safety. The largest impacts to the study were on the more isolated systems in NWVI, including the Marble River. The extreme weather was not such a detrimental factor in the other study populations such as Leiner and Tranquil.

3.1.1 Tag Application

Chinook in the study populations were captured through beach seine and angling. Fish were tagged starting about mid-September when survey crews began observing migration to the river. A total of 5, 25 and 30 radio+spaghetti tags were applied to a portion of the Marble, Leiner and Tranquil populations, respectively. A total of 62, 16 and 20 spaghetti tags alone were applied to a portion of the Marble, Leiner and Tranquil populations, respectively (Table 3).

3.1.2 Spawner Survey Results

A total of 4, 9 and 9 spawner surveys were conducted on the Marble, Leiner and Tranquil Rivers, respectively, during snorkel swims on the accessible length of the river. The maximum number of Chinook observed was 1112, 276 and 121 on the Marble, Leiner and Tranquil Rivers, respectively (Table 4). For the NWVI systems extreme weather was a factor and the swim crew on the Marble did not meet its survey objective. During a significant portion of the run, crews could not safely swim the index section. On the other hand, crews in the Leiner and Tranquil systems were able to conduct spawner surveys over the duration of the run.

For the most part crews were able to observe external tags that were applied. However, crews in the Marble reported difficulty differentiating between the yellow and green tags at depth. Specific tag application and tag-resight data are summarized in Table 5. Totals include live and dead spawners that were observed. Insufficient carcasses were recovered to estimate tag loss.

3.1.3 Telemetry Surveys

After radio tag application and corresponding external (spaghetti tag) mark application and before spawner surveys, telemetry surveys were conducted. Telemetry results were used to estimate survey life based on the difference between radio application and time of death. An additional survey life estimate based on telemetry was a trapezoidal approximation of the area under the tag curve based on live tag detection divided by the number of tags applied and detected at least once. A total of 6 telemetry surveys were conducted on the Leiner River and 9 on the Tranquil River, and 8 on the Marble (Table 6). Telemetry continued on the Marble even while the river was inaccessible to swimmers due to flooding.

3.2 DATA AND ANALYSIS

3.2.1 Age and Length Composition

To reduce tagging stress, biological samples were only collected from carcasses (Tranquil) or when broodstock were collected (Leiner) (Table 7). Average post-orbital length for the Leiner population was 765 and 652.5 mm for females and males, respectively. Average post-orbital length for the Tranquil population was 757.5 and 740 mm for females and males, respectively. The average age composition for the Leiner River was 30%, 40%, 20% and 10% age 3_1, 4_1, 5_1 and 6_1 fish, respectively. Due to the poor conditions of the carcasses encountered in the Tranquil River insufficient scales were collected to produce an estimate of the age distribution. No carcasses were recovered from the Marble.

3.2.2 Survey Life Estimates

Survey life was estimated for the Marble, Leiner and Tranquil study populations. The average estimated survey life was 36, 14.7 and 21.3 days for the Marble, Leiner and Tranquil populations, respectively based on radio tags and the area under the tag curves of the radio and spaghetti tags (Table 8). The average estimated survey life was 25, 20.2 and 29.5 days for the Marble, Leiner and Tranquil populations, respectively based on the unimodal maximum likelihood model.

3.2.3 Observer Efficiency Estimates

Observer efficiency of the spawner survey crews was estimated for the Marble, Leiner and Tranquil systems. Observer efficiency varied across surveys. Across surveys within a study population, the weighted average estimated observer efficiency was 37%, 76% and 75% for the Marble, Leiner and Tranquil populations, respectively (Table 9). (Averages were weighted by total number of Chinook observed in the survey. However, in practice, each survey is expanded by an individual estimate of observer efficiency.)

3.2.4 Environmental Correlates of Observer Efficiency

Prior to each spawner survey, snorkel crews collected environmental data, including horizontal distance of visibility under water (for each swimmer), water temperature, water flow, gauge height, and pool Secchi depth (Table 10). These data were used in regression analysis to develop a relationship between the environmental correlates and the estimated observer efficiency.

The relationships between survey life and environmental correlates for the Leiner and Tranquil Rivers are displayed in Figure 2, Figure 3, respectively. For all systems there was a positive relationship between observer efficiency and the horizontal visibility/discharge (HV/Q) index.

3.2.5 Escapement Estimates

Escapement was estimated for the study populations using data generated from the study and a number of alternative estimation models (Table 11, Table 12). These estimates were compared within and across the study populations.

For the Marble River, the trapezoidal AUC method with qualitative assessment of observer efficiency and survey life (i.e. the method normally used to generate WCVI escapement estimates) yielded an escapement estimate of 3,905. The trapezoidal AUC method with quantitative assessment of observer efficiency and survey life based on 2011 measurements yielded an escapement estimate of 3,503. The mark-recapture method using the Chapman modification of the Petersen estimator (Ricker, 1975 and Cousens et al., 1982) using the radio tag information to estimate the proportion of tags available yielded an estimate of 3,112 (averaged over the three sampling events). The unimodal and bimodal maximum likelihood escapement estimation models yielded estimates of 3,789 and 3,080 respectively.

For the Leiner River, the trapezoidal AUC method with qualitative assessment of observer efficiency and survey life yielded an escapement estimate of 392. The trapezoidal AUC method with quantitative assessment of observer efficiency and survey life based on 2011 measurements yielded an escapement estimate of 467. The mark-resight method yielded an estimate of 480 (95% CI 370-660). The unimodal and bimodal maximum likelihood escapement estimation models yielded estimates of 288 and 375 respectively.

For the Tranquil River, the trapezoidal AUC method with qualitative assessment of observer efficiency and survey life yielded an escapement estimate of 221. The trapezoidal AUC method with quantitative assessment of observer efficiency and survey life based on 2011 measurements yielded an escapement estimate of 269. The mark-resight yielded an estimate of 215 (95% CI 178-278). The unimodal and bimodal maximum likelihood escapement estimation models yielded estimates of 121 and 160 respectively.

3.2.6 Comparison of Escapement Estimates with Provisional Habitat Based Escapement Targets

The maximum estimated escapement estimates for 2011 were compared with provisional habitat-based escapement targets that are defined for WCVI Chinook populations using the model of Parken et al. (2006). The escapement estimates were also compared with the Chinook rebuilding goals defined under the 1985 PST (Table 14). With the exception of the Marble River (located in the far north of WCVI, DFO Statistical Area 27), those populations, that do not receive any form of stock enhancement are well below both provisional targets. On the other hand, populations that receive some level of enhancement, including Leiner and Tranquil Chinook, or at or above provisional escapement targets. However, the Tranquil population has declined over the last several years after the enhancement program there was terminated. This observation is consistent with the current stock assessment of WCVI Chinook.

4.0 CONCLUSION / RECOMMENDATIONS

The objective of this study was to collect additional survey data to improve the estimation of escapement of WCVI chinook populations. Other than the Robertson Creek CWT Indicator stock, escapement to WCVI chinook systems is estimated using the Area-Under-the-Curve (AUC) method to expand counts gathered through stream surveys (usually gathered during snorkel surveys conducted about once per week for 4 to 6 weeks).

Field conditions in 2011 were not ideal for escapement surveys. Extremely high rainfall led to flood events, which impeded both road and river access to survey sites. Although survey conditions were not ideal, the study objectives were achieved for the most part for the populations. The results are informative and will help inform the improvement of the overall WCVI escapement survey design. For those systems where the study design was successfully implemented, it was possible to directly measure survey life and observer efficiency, two key parameters that are subjectively estimated in the current WCVI AUC surveys.

Although survey life is not directly measured each year during WCVI escapement surveys, the range of survey life estimates that are applied are based on previous studies (e.g. Trouton et al. 2007 and earlier unpublished work). Generally speaking, for larger WCVI systems and for Chinook, measured survey lives are longer than for other systems and species on Vancouver Island. Survey life was estimated at about 8 to 12 days for coho systems on the east coast of Vancouver Island (Irvine and Perrin, 1990) whereas for WCVI Chinook systems survey life is typically estimated at between 15 to 30 days (Trouton et al. 2007 and unpublished studies). From year to year when no empirical data are available, whether the lower or higher range is applied depends on a qualitative assessment of survey conditions. For example, prolonged summer drought through September leading to delayed migration on the first freshet would result in application of a lower survey life. A higher survey life would be applied with the observation of periodic migration to the river over the prolonged period.

For this study, it was possible to estimate survey life for all three of the study systems. Telemetry results indicate the survey life estimates where within the range that is typically applied for WCVI systems (i.e. 20 to 25 days).

Crews assess their observer efficiency based on a qualitative assessment of survey conditions. Consistent with the findings in 2010, crews tend to over-estimate their observer efficiency, particularly when survey conditions deteriorated later on during the migration period. It was interesting that surveyors did not generally report major increases or decreases in their observer efficiency despite significant changes in river conditions. However, the changes in river conditions were described by measuring parameters such as Secchi depth, horizontal visibility and discharge. Following Korman et al. (2007), observer efficiency was well-correlated with an index of river conditions described by horizontal visibility/discharge. Further work to develop this relationship (i.e. through more direct measurement of observer efficiency, river conditions) will greatly improve the quality of AUC estimates of Chinook for WCVI populations. Survey conditions can be indexed by measuring horizontal visibility and discharge for each survey at much lower cost than directly estimating observer efficiency through telemetry studies.

When the ‘qualitative’ (i.e. standard approach with assumed OE and SL) AUC estimate of escapement for the study populations was compared with estimates generated through either i) using directly measured OE and SL; ii) maximum likelihood estimate; iii) mark-resight or iv) mark-recapture, all the methods produced estimates within the similar range, including the ‘quantitative’ AUC estimate using directly measured OE and SL. In 2010 the qualitative AUC estimates were roughly 50% less than the estimates using alternative means, probably due to difficult survey conditions. In 2011, survey conditions were also challenging, but not quite as extreme as 2010, so the results of the multiple estimation methods were generally comparable.

For management purposes, it is important to understand the magnitude and consistency of bias in escapement estimates when determining the status of a population relative to biological benchmarks (e.g. S_{MSY} or PSC rebuilding goals). While conditions are often challenging on the WCVI for spawner surveys, 2010 was particularly difficult and the effects of underestimating observer efficiency or overestimating survey life may have been greater than average. The results of the 2011 study, during which conditions were more typical, show that the qualitative AUC estimate is a reasonable number on which to base management decisions.

Although the flooding was particularly extreme in 2010, high rainfall during the peak river migration is typical of the study area and, along with isolation, one of the logistical challenges along of working on WCVI river systems. These challenges result in safety, access and expense issues in addition to survey design challenges. Some alternative escapement estimation methods (e.g. mark-recapture or counting weirs) are more vulnerable to these challenges than the snorkel-survey method currently employed. On the WCVI high discharge rates generally lead to unsuccessful dead-pitch surveys. Therefore, it is often difficult to retrieve sufficient carcasses for tag loss estimation to support mark-resight (or recapature) estimation methods. Also, in addition to the significant expense associated with mark-recapture or counting weir programs, the behaviour of fish that are handled extensively may be altered sufficiently to bias the estimate.

We suggest that while the short-term intensive studies such as the mark-recapture and mark-resight programs currently being conducted on WCVI systems will help validate current escapement estimates, they are not sustainable in the long-term. The magnitude of bias in the AUC estimates is mostly determined by the estimation of annual survey life. Our objective is to improve our understanding of annual variation in survey life and conditions related to increased/decreased survey life from year to year. If for many systems the assumption of 20 to 30 day survey life is valid, then the magnitude of bias in the AUC estimate is largely dependent on whether a good peak count was achieved since survey life is not much shorter than duration of the migration period. On the other hand if there are systems for which survey life has been grossly over-estimated then these studies may help us classify the conditions or characteristics of the systems that result in lower survey life. The initial work conducted in 2010 and 2011 suggests that we will be able to develop a good relationship in between OE and survey conditions. If the relationship is well established, then measuring environmental correlates to inform observer efficiency assumptions is a relatively simple and inexpensive improvement to the current AUC program.

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6.0 ACKNOWLEDGEMENTS

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7.0 TABLES AND FIGURES

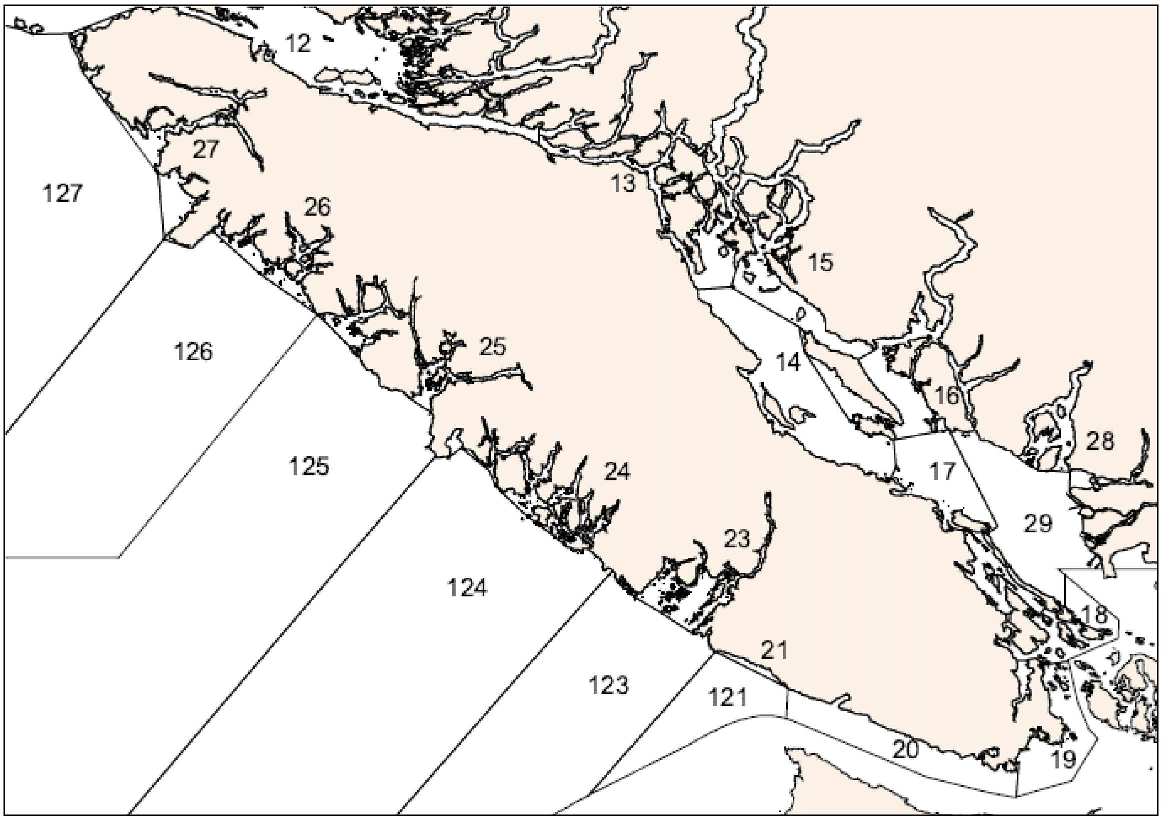

Figure 1. Vancouver Island and DFO Statistical Areas.

Table 1. Escapement estimates to WCVI Chinook indicators (1995 to 2011).

Statistical Area	System	Year																	*Average*
		1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	
20	**San Juan**	710	950	1,080	4,570	1,560	370	810	1,457	1,930	540	1,200	4,520	1,890	1,700	2,870	1,300	560	*1,650*
23	**Nahmint**	210	260	240	1,010	930	70	230	520	660	1,220	160	490	170	150	100	470	640	*440*
	Sarita	140	490	1,870	2,420	770	300	1,530	3,300	3,710	3,450	1,220	3,300	1,630	1,000	730	900	1,300	*1,650*
	Toquart	100	270	510	310	160	100	170	200	590	700	-	860	-	-	-	320	-	*250*
24	**Bedwell/Ursus**	290	530	280	310	160	140	260	130	140	140	70	100	40	70	40	50	90	*170*
	Megin	320	160	270	370	230	160	-	20	30	70	40	120	10	20	20	10	50	*110*
	Moyeha	90	240	80	160	240	90	120	50	160	360	120	90	110	150	60	190	70	*140*
	Tranquil	450	650	940	850	750	1,780	2,080	190	1,780	1,130	640	410	250	220	210	230	210	*750*
	Cypre	10	10	20	20	10	-	640	30	500	490	500	420	870	450	250	440	1,100	*340*
25	**Burman**	590	720	2,350	3,210	2,400	210	110	440	770	2,640	640	520	350	520	1,800	3,030	2,020	*1,310*
	Leiner	410	720	520	380	820	130	390	940	400	630	330	180	180	270	730	430	390	*460*
	Sucwoa	440	340	50	20	70	220	110	40	-	330	40	-	150	80	-	10	230	*130*
	Tahsis	530	770	720	590	1,730	1,220	390	760	760	910	180	140	130	280	780	380	220	*620*
	Tlupana	140	40	70	70	50	90	360	1,160	330	470	1,040	1,050	320	180	10	40	30	*320*
	Zeballos	160	350	860	670	690	60	100	150	70	390	90	450	440	470	120	120	110	*310*
26	**Artlish**	100	50	400	300	540	80	140	40	380	450	200	230	160	200	210	110	100	*220*
	Kaouk	270	220	560	820	450	110	410	250	360	300	490	540	190	260	550	190	300	*370*
	Tahsish	600	290	520	1,430	880	390	240	310	440	500	120	80	230	380	80	360	260	*420*
27	**Marble**	1,630	3,970	2,640	5,300	4,190	2,570	1,450	2,490	1,750	3,660	2,350	3,070	2,760	2,680	3,440	3,560	3,910	*3,020*
	Colonial/Cayeghle	80	70	40	170	880	530	570	380	600	1,370	-	320	170	160	630	520	410	*410*

Table 2. Provisional habitat-based escapement targets for WCVI Chinook indicators (based on Parken et al. 2002).

River System	Area	Survey Length	Barrier Distance	Effecttive Watershed Area (Km^2)	Optimal CK Escapements Smsy (80% confidence interval)	Replacement CK Escapements Srep (80% confidence interval)
Sarita River	23	6000	6000	99	643 (522 - 791)	2,028 (1,657-2,481)
Nahmint River	23	3500	3500	193	1,189 (988 - 1,430)	3,361 (3,064-4,375)
Bedwell R / Ursus C	24	17500	17500	98	638 (518 - 786)	2,015 (1,646-2,466)
Moyeha River	24	9000	11000	181	1,121 (930 - 1,352)	3,460 (2,890-4,143)
Megin River	24	10000	16000	135	857 (704 - 1,044)	2,674 (2,211-3,235)
Tranquil Creek	24	3500	8000	61	415 (331 - 521)	1,333 (1,069-1,662)
Cypre River	24	7000	9700	60	405 (323 - 509)	1,303 (1.044-1,626)
Burman River	25	7500	7500	242	1,459 (1,221 - 1,744)	4,458 (3,757-5,290)
Tahsis River	25	2000		77	512 (412 - 636)	1,629 (1,319-2,013)
Leiner River	25	1930	1930	105	681 (555 - 837)	2,145 (1,758-2,619)
Zeballos River	25	1500	1500	193	1,188 (987-1,429)	3,658 (3,061-4,371)
Kaouk River	26	9000	17000	115	741 (605 - 907)	2,325 (1,912-2,829)
Artlish River	26	10600		125	796 (652 - 972)	2,491 (2,054-3,022)
Tahsish River	26	6000	6280	106	690 (562 - 847)	2,171 (1,780-2,649)
Marble River	27	4915		194	1,191 (990 - 1,434)	3,669 (3,071-4,384)
Cayeghle/Colonial	27	19300		85	560 (452 - 694)	1,778 (1,445-2,188)

Srep is the maximum escapement in the absence of any harvest (human impacts).

Table 3. Number and date of tag application in study populations.

Population	Date	Radio Tags	Spaghetti Tags
Marble	9/10/2011	1	9
	9/13/2011	4	29
	9/16/2011		5
	9/17/2011		9
	9/18/2011		3
	9/20/2011		7
	Total	**5**	**62**
Leiner	9/17/2011	25	16
	Total	**25**	**16**
Tranquil	10/1/2011	21	11
	10/25/2011	9	9
	Total	**30**	**20**

Table 4. Spawner Survey Dates and Observations on Study Populations.

System	Survey Date	Total Adult CN	Unmarked	Marked
Marble	9/2/2011	407		
	9/14/2011	1112	1094	18
	9/21/2011	973	957	16
	10/21/2011	525	521	4
Total	4			
Leiner	9-Sep-11	51		
	16-Sep-11	276		
	18-Sep-11	258	227	31
	29-Sep-11	200	190	10
	2-Oct-11	126	117	9
	7-Oct-11	47	45	2
	14-Oct-11	14	14	0
	25-Oct-11	1	1	0
	15-Nov-11	2	2	0
Total	9			
Tranquil	15-Sep-11	0		
	7-Oct-11	121	95	26
	14-Oct-11	108	87	21
	23-Oct-11	114	107	7
	31-Oct-11	50	26	24
	6-Nov-11	22	18	4
	12-Nov-11	7	7	0
	15-Nov-11	3	3	0
	19-Nov-11	5	5	0
	1-Dec-11	0	0	0
Total	9			

Table 5. Detailed mark-resight data for the study populations, Marble, Leiner and Tranquil.

Population	Date	Application				Re-sight				
		Radio 1	Radio 2	Non-radio 1	Non-radio 2	Event 1	Event 2	Event 3	Event 4	Event 5
						09/14	09/21	10/21		
Marble	09/10	1								
				9						
	09/13	4				1	1	1		
				29		17	15	3		
	09/16			5						
	09/17			9						
	09/18			3						
	09/20			7						
	10/22									
	Total	**5**	**0**	**62**	**0**					
Leiner						09/18	09/29	10/02	10/07	10/14
	09/17	25				20	5	2		
	09/17			16		11	5	7	2	
	Total	**25**	**0**	**16**	**0**					
Tranquil						10/07	10/14	10/23	10/31	11/06
	10/01	21				17	14	6	2	2
	10/01			11		9	7	1	2	1
	10/25		9						9	2
	10/25				16				11	10
	Total	**21**	**9**	**11**	**16**					

Table 6. Telemetry survey dates Leiner, Tranquil, and Marble Rivers.

System	Survey Date
Leiner	7-Oct-11
	14-Oct-11
	23-Oct-11
	31-Oct-11
	6-Nov-11
	12-Nov-11
	15-Nov-11
	19-Nov-11
	1-Dec-11
Leiner Total	9
Tranquil	18-Sep
	29-Sep-11
	2-Oct-11
	7-Oct-11
	14-Oct-11
	25-Oct-11
Tranquil Total	6
Marble	22-Sep-11
	23-Sep-11
	28-Sep-11
	29-Sep-11
	4-Oct-11
	14-Oct-11
	18-Oct-11
	27-Oct-11
Marble Total	8

Table 7 Length and age data collected from study populations.

	Female POH (mm)		Age Dist			Male POH (mm)		Age Dist				
	Mean	SD	**4-1**	**5-1**	*n*	Mean	SD	**3-1**	**4-1**	**5-1**	**6-1**	*n*
Tranquil	757.5	92	n/a		4	740	n/a	n/a				1
Leiner	765	71	50%	50%	2	652.5	98	30%	40%	20%	10%	8

Table 8. Average estimated survey life Marble, Leiner and Tranquil Rivers, based on radio telemetry surveys and swims. AUC-Tag is the trapezoidal approximation of the area under the tag curve divided by the number of tags. Observed is the average number of days individual tags were active.

System	Radio Telemetry/External Mark Resight						
	Survey Type	**Estimate Type**	**Estimate**	**St. Dev**	***n***	**St. Error**	**95% CI**
Marble	Telemetry	AUC-Tag	37.9		4		
	Telemetry	Observed	34.0	16.2	4	8.1	15.9
		Average	36.0				
Leiner	Telemetry	AUC-Tag	11.4		21		
	Telemetry	Observed	15.5	3.4	21	0.7	1.5
	Swim	AUC-Tag	17.9		16		
		Average	14.7				
Tranquil	Telemetry	AUC-Tag	25.0		21		
	Telemetry	Obs Event 1	27.5	10.4	21	2.3	4.4
	Telemetry	Obs Event 2	10.8	8.0	9	2.7	5.2
	Telemetry	Obs Total	22.5	12.3	30	2.2	4.4
	Swim	AUC-Tag	16.5		32		
		Average	21.3				

Table 9. Observer efficiency estimates for study populations. The average observer efficiency is weighted by the total number of adult Chinook observed during each survey.

System	Date	Total adult chinook observed	Known radio-tagged chinook	Observed radio-tagged chinook	Observer Efficiency
Marble	9/14/2011	1112	3	1	33%
	9/21/2011	973	3	1	33%
	10/21/2011	525	2	1	50%
Weighted Average					37%
Leiner	9/9/2011	51			
	9/16/2011	276			
	9/18/2011	258	20	20	100%
	9/29/2011	200	10	5	50%
	10/2/2011	126	3	2	67%
	10/7/2011	47	2	0	
	10/14/2011	14			
	10/25/2011	1			
	11/15/2011	3			
	12/2/2011	0			
Weighted Average					76%
Tranquil	9/15/2011	0			
	10/7/2011	121	19	17	89%
	10/14/2011	108	15	14	93%
	10/23/2011	114	13	6	46%
	10/31/2011	50	17	11	65%
	11/6/2011	22	7	4	
	11/12/2011	7	7	0	
	11/15/2011	3	5	0	
	11/19/2011	5	4	0	
	12/1/2011	0	2	0	
Weighted Average					75%

Table 10. Environmental data collected by spawner survey crews.

System	Date	OE	Horizontal visibility (m)	River Height (m)	Distance (m)	Time for flow (s)	River flow (m\s)	Wetted area (m^2)	SEF station discharge (m^3/s)	SEF HV/Q
								%bankfull		
Marble	09/02		8.5	normal				70%		
	09/14	33%	12	below norm				50%		
	09/21	33%	6.3	normal	20	8.15	2.45	60%		
	10/21	50%	7.2	above norm				85%		
Leiner										
	09/09		10	0.53	10	28.1	0.36	19.42	6.91	1.45
	09/16		15	0.51	10	33.9	0.30	19.21	5.67	2.64
	09/18	100%	9	0.58	10	24.9	0.40	19.94	8.01	1.12
	09/29	50%	5	0.7	10	13.0	0.77	21.20	16.26	0.31
	10/02	67%	7	0.58	10	20.8	0.48	19.94	9.60	0.73
	10/07		6	0.63	10	13.8	0.73	20.47	14.89	0.40
	10/14		6	0.66	10	14.8	0.68	20.78	14.04	0.43
Tranquil	09/15		12	0.56	10	42	0.24	28.03	6.67	1.80
	10/07	89%	9	0.73	10	11	0.91	33.47	30.43	0.30
	10/14	93%	8	0.74	10	12	0.83	33.79	28.16	0.28
	10/23	46%	6	0.77	10.0	7.0	1.43	34.76	49.65	0.12
	10/31	65%	6.5	0.75	10.0	8.0	1.25	34.1	42.64	0.15
	11/06		9	0.64	10.0	22.0	0.45	30.59	13.90	0.65
	11/12		5	0.82	10.0	7.0	1.43	36.36	51.95	0.10
	11/15		7	0.68	10.0	13.0	0.77	31.87	24.51	0.29
	11/19		7	0.67	10.0	14.0	0.71	31.55	22.53	0.31
	12/01		4	0.76	10.0	10.0	1.00	34.44	34.44	0.12

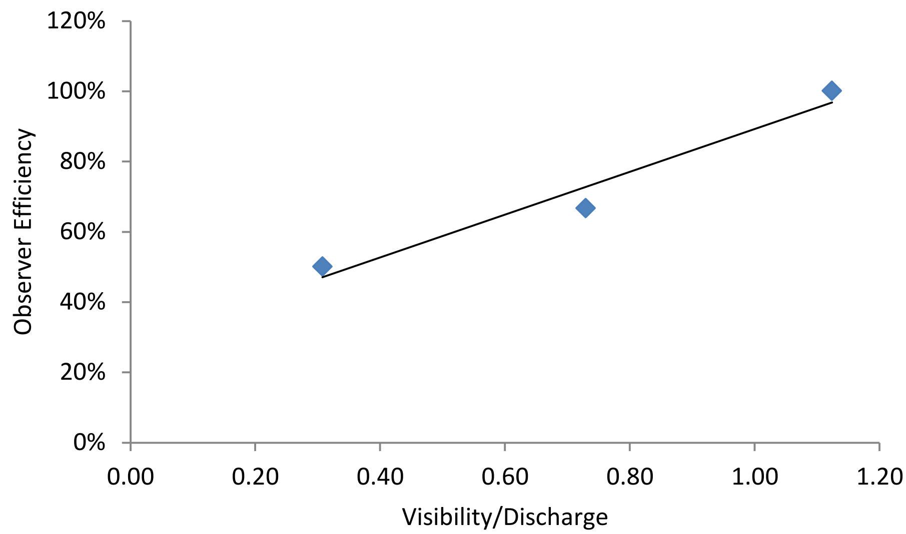

Figure 2. Relationship between river conditions and observer efficiency of Chinook for the Leiner River (R^2 = 0.96).

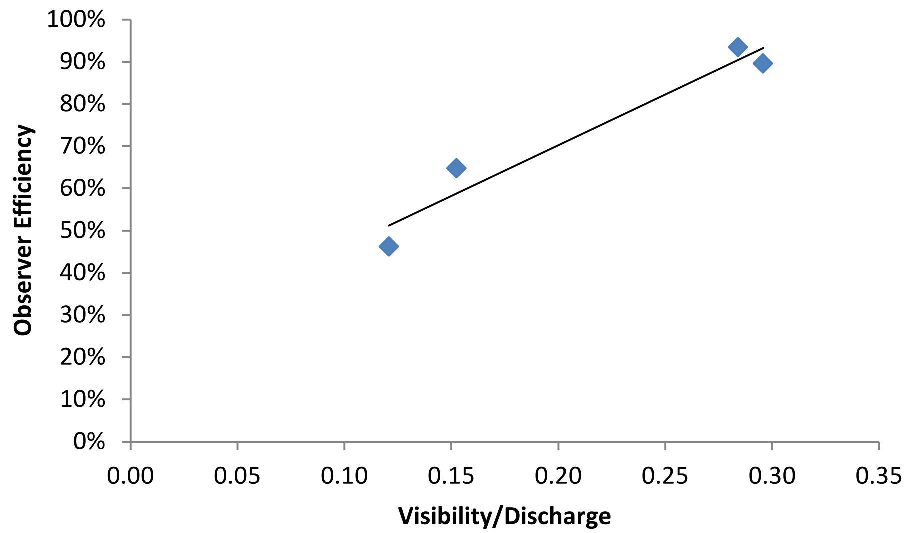

Figure 3. Relationship between river conditions and observer efficiency of Chinook for the Tranquil River (R^2 = 0.94).

Table 11. Area-under-the-curve (AUC) estimates for study systems.

System	Survey Date	Raw	Qualitative AUC		Quantitative AUC	
		Total Adult CN	Observer Efficiency	Expanded Adult CN	Observer Efficiency	Expanded Adult CN
Marble	9/2/2011	407	31%	1330		407
	9/14/2011	1112	79%	1404	33%	3370
	9/21/2011	973	40%	2439	33%	2948
	10/21/2011	525	25%	2134	50%	1050
Total	4					
Max Observed		1112		2439		3370
Survey Life				35		34
AUC Estimate				3905		3503
Leiner	9/9/2011	51	80%	64		51
	9/16/2011	276	81%	341		276
	9/18/2011	258	81%	319	100%	258
	9/29/2011	200	61%	327	50%	400
	10/2/2011	126	81%	156	67%	189
	10/7/2011	47	81%	58		47
	10/14/2011	14	90%	16		14
	10/25/2011	1	90%	1		1
	11/15/2011	3	90%	3		3
	12/2/2011	0	90%	0		0
Total	10					
Max Observed		276		341		400
Survey Life				20		15.5
AUC Estimate				392		467
Tranquil	9/15/2011	0	100%	0		0
	10/7/2011	121	95%	127	89%	135
	10/14/2011	108	95%	114	93%	116
	10/23/2011	114	93%	122	46%	247
	10/31/2011	50	93%	54	65%	77
	11/6/2011	22	95%	23		22
	11/12/2011	7	95%	7		7
	11/15/2011	3	95%	3		3
	11/19/2011	5	95%	5		5
	12/1/2011	0	95%	0		0
Total	10					
Max Observed		121		127		247
Survey Life				20		21.8
AUC Estimate				221		269

Table 12. Comparison of escapement estimates for study systems generated through different analytical models.

System	No. Surveys	Max. Observed	AUC (Qual)	AUC (Quan)	ML - Unimodal	ML - Biomodal	Mark-Resight	Mark-Resight 95% CI
Marble	4	1,112	3,905	3,503	3,789	3,080	n/a	
Leiner	10	276	392	467	288	375	463	(370-660)
Tranquil	10	121	221	269	121	160	215	(178-278)

Table 13. Comparison of maximum estimated escapement (2011) and qualitative AUC estimate.

2011 Max Estimated Escapement	2011 Qualitative AUC Escapement	Ratio (Qual AUC: Max Est.)
3,905	3905	1.00
467	392	0.84
269	221	0.82

Table 14. Comparison of provisional S_{MSY} Chinook escapement targets for study systems with maximum estimated escapement in 2011.

System	Optimal CK Escapement (Smsy)	80% confidence interval	2011 Max Estimated Escapement	Ratio (Observed: Optimal)
Marble	1,191	990-1434	3,905	3.3
Leiner	681	555-837	467	0.7
Tranquil	415	331-521	269	0.6

APPENDIX 1
OPERATIONAL SUMMARY

Project Deliverables

Field study work was completed, as the modeling objectives were largely completed in 2010.

The specific objectives of the field study were to:

- Estimate total escapement of adult Chinook through a mark-resight study on selected systems;
- Quantify Chinook survey life and observer efficiency for selected systems;
- Determine potential environmental correlates with observer efficiency;
- Compare the mark-resight, normative AUC (5 swims surveys) and extended AUC (10-12 swims surveys) escapement estimates.

The specific objectives of the analytical model development were to:

- Identify and use scientifically defensible procedures to provide AUC escapement estimates and associate levels of uncertainty for selected WCVI systems surveyed recently.
- Based on the results obtained, assess the relative merits of alternative survey procedures that can be used to estimate total escapement to selected WCVI conservation units (CUs).
- Determine the relative benefits of complementary surveys to be initiated shortly in terms of gains in accuracy and precision of future AUC escapement estimates for selected CUs.

Project Schedule

- Field implementation ran per schedule. However, full implementation of the study design (particularly on the Marble River), was impeded due to extreme weather conditions.
- Reporting on the project (i.e. to the SEF, PSC) did not ran per schedule. Key issues/challenges are related to staff turnover and completing priorities within DFO.

QA/QC

- All contractors working on the project were trained prior to implementation – i.e. a one-day work shop was conducted to communicate objectives, methodology, protocols, etc.
- Field work conducted by contractors is monitored periodically by DFO technicians through an auditing process – i.e. DFO technicians conduct site visits to monitor crew work.

Monitoring and evaluation

- All contract performance is monitored under normal Government of Canada procedures.
- Field crews and contractors are given feedback on the quality of their work through audit reports.
- The quality of data sets is monitored through the evaluation of the data (i.e. analysis is conducted by DFO staff). Contractors are required to submit data weekly so that it can be evaluated in a timely fashion.

Benefits

There have been several benefits generated from this project:

- The analytical work resulted in the development of a robust model that can be used to explore and describe the uncertainty in WCVI chinook escapement estimates. It is a significant improvement over previous models that have been used and will be used to examine past data sets as well.
- The modeling work resulted in several recommendations to improve the survey design WCVI escapement monitoring. These recommendations were implemented in 2011.
- The field work has provided empirical data to better understand the variation in observer efficiency and survey life. This information is required to estimate uncertainty in escapement estimates (either modeled or through a direct 'AUC' estimate).
- Preliminary results of the field studies show a promising relationship between environmental correlates and observer efficiency. The further development of this relationship in 2012 field will allow improved application of estimation models without annual implementation of expensive field studies to directly estimate observer efficiency.
- The preliminary results of this study (and related SSP studies) have provided increased confidence in the current WCVI chinook escapement estimation. After a presentation of the results of this study, members of the Chinook Technical Committee conceded that they agree the abundance of WCVI wild chinook is low.
- Given the results of these studies, the Sentinel Stock Committee has now moved toward the model implemented under this design (i.e. they recognized the value of the work completed so far and better understand the challenges of implementing escapement surveys on the WCVI).

Financial Statement (EXCEL workbook, submitted)