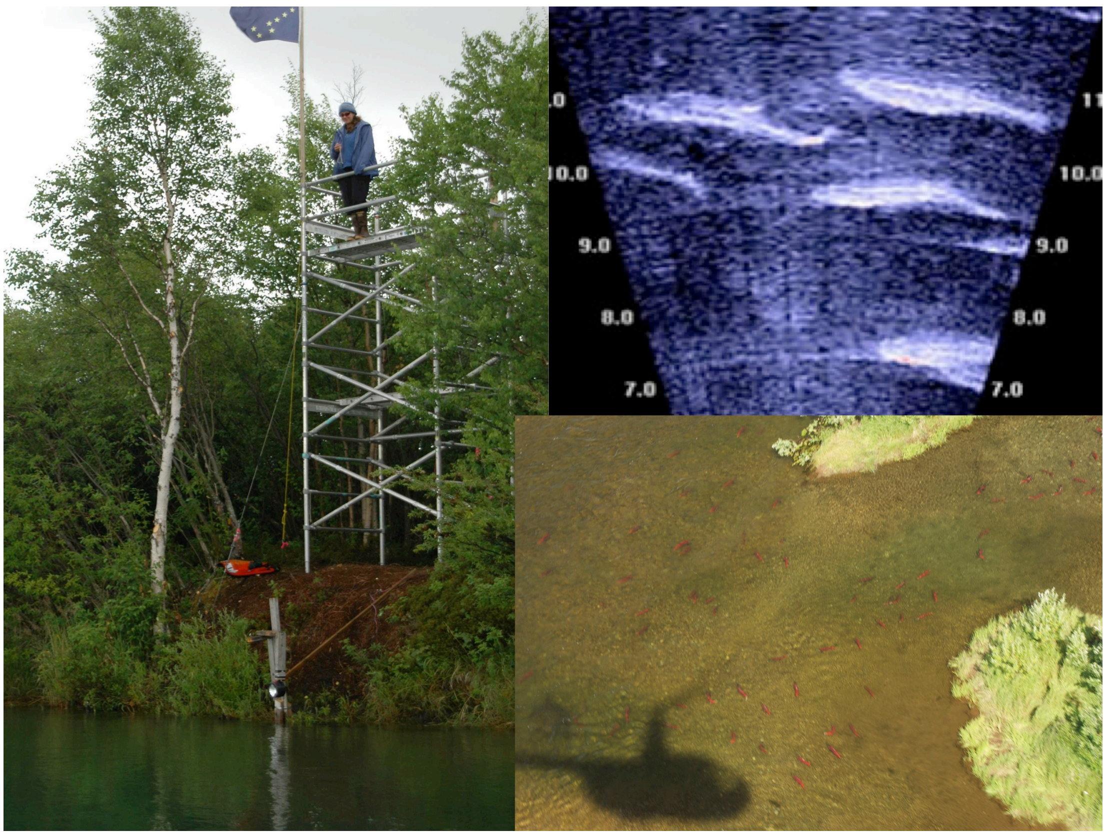
Assessing Reliability of Pebble Limited Partnership's Salmon Escapement Studies



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Executive Summary

Basic Issue	How many salmon spawn in rivers draining the Pebble deposit?
Approach, data quality, and intended uses	Total spawning salmon or escapement was determined using intermittent aerial helicopter surveys in main stem rivers and select tributaries; most tributaries were not surveyed. Aerial surveys are unreliable methods for estimating total salmon escapement due to bias (undercounting of fish) and low precision (high variation). Total escapement using aerial count data was estimated with Area-Under-the-Curve (AUC) models (Trapezoidal and Maximum Likelihood). Detailed reproducible methods are not presented. A non-standard Mean Index Count (MIC) was used to estimate relative escapement. Results were compared to total escapement estimates for the Nushagak and Kvichak rivers by ADFG. Because the MIC estimates an unknown proportion of total escapement, has unknown bias and variance, and has unreasonable assumptions it is not a scientifically valid method with which to document baseline salmon escapement. These issues also render MIC results incomparable to the scientifically rigorous passage counts used to determine total escapement to the Nushagak and Kvichak Rivers.
Primary data gaps	Total salmon escapement is not estimated. No detailed methods, models, assumptions, or results are presented for total escapement estimates (AUC). Such data were presented in the past, but were not included in the EBD. Results of all surveys (e.g., date flown, number and species of salmon counted, observer etc.) are unavailable.
Principle findings and recommen-dations	Total escapement was not estimated although historic data exists indicating hundreds of thousands of salmon may spawn in the study area. The AUC Trapezoidal model can provide a "fair" total escapement estimate. Studies should be designed and implemented to overcome issues with bias and precision such that 2004-2008 aerial data can be used to provide a total escapement estimate. . The MIC should not be used, as it is statistically invalid and potentially misleading. Aerial escapement methods should be discontinued. Future studies should employ scientifically rigorous daily salmon passage counts using weirs, towers or sonar. Alaska Department of Fish and Game should conduct counts that include bias and precision estimates.

Introduction

Bristol Bay Salmon Escapement

Bristol Bay rivers sustain major commercial, subsistence and sport fisheries. The world's largest all-wild sockeye salmon runs, comprising about 51% of world commercial harvest, originate in Bristol Bay (Pinsky et al. 2009, Ruggerone et al. 2010). Commercial harvests during 1990-2010 averaged 25.8 million sockeye, 64,000 Chinook, 1.3 million chum, 88,000 coho and 182,000 (even year) pink salmon (Salomone et al. 2011). During the same period, subsistence fishers harvested an average of about 140,000 salmon, preserving most for winter following thousands of years of tradition (Salomone et al. 2011). Sport fishers spent approximately $61 million dollars in 2005 for the opportunity to fish Bristol Bay waters (Duffield et al. 2007).

Bristol Bay salmon management is globally recognized as sustainable (Global Trust 2011) and is the product of careful scientific management by the Alaska Department of Fish and Game (ADFG). A primary goal of harvest management is to ensure the number of fish that escape the fishery to spawn (escapement) meet sustainability goals (Baker et al. 2009). The Alaska Department of Fish and Game annually collects accurate (unbiased) and precise (low variability) daily counts of total salmon spawning escapement to all major Bristol Bay rivers. These counts, made using towers, sonar, and/or weirs are generally accurate to within ± 10% of actual escapement 95% of the time (Anderson 2000, Woody 2007, Reynolds et al. 2007, Baker et al. 2009, Brazil and Buck 2011). This scientific data is the cornerstone of Bristol Bay fisheries management as it is used to estimate salmon productivity, establish sustainable harvest levels, estimate future run size, evaluate success of conservation decisions, and to assess management decision impacts. ADFG management has conserved both Bristol Bay salmon biomass and diversity since the 1950s (Minard and Meacham 1987, Hilborn 2006, Schindler et al. 2010). Intact salmon habitats also contribute to Bristol Bay's sustained salmon productivity (Hilborn et al. 2003, Schindler et al. 2010).

Since 1956, the Nushagak and Kvichak Rivers together produced over 40% of total Bristol Bay sockeye salmon production (ADFG 2011). Escapement to the Nushagak River is estimated using sonar (Brazil and Buck 2011) while escapement to the Kvichak River is estimated using counting towers (Anderson 2000, Fair 2003, Woody 2007). Because adult salmon passage is counted daily at set reference points and collection methods are statistically rigorous, sonar and tower counts are considered reliable scientific methods for estimating total salmon escapement (see Table 2 in Parsons and Skalski 2010).

Plans to develop a 10.8 billion ton low-grade copper-gold deposit (Pebble) in headwaters of the Nushagak and Kvichak River watersheds (Figure 1; Ghafarri et al. 2011, DNR 2012) can impact salmon productivity as measured by total escapement (ADFG 2012). In anticipation of mine permit and Environmental Impact Statement requirements Northern Dynasty Mines Inc. (NDM) and later Pebble Limited Partnership (PLP) initiated salmon escapement studies in 2004 (NDM 2005), results were presented annually to agencies through 2007 (NDM 2005, McLarnon 2007, DNR 2012). Recently, PLP released an

Environmental Baseline Document (EBD) that included escapement studies through 2008 (PLP 2012).

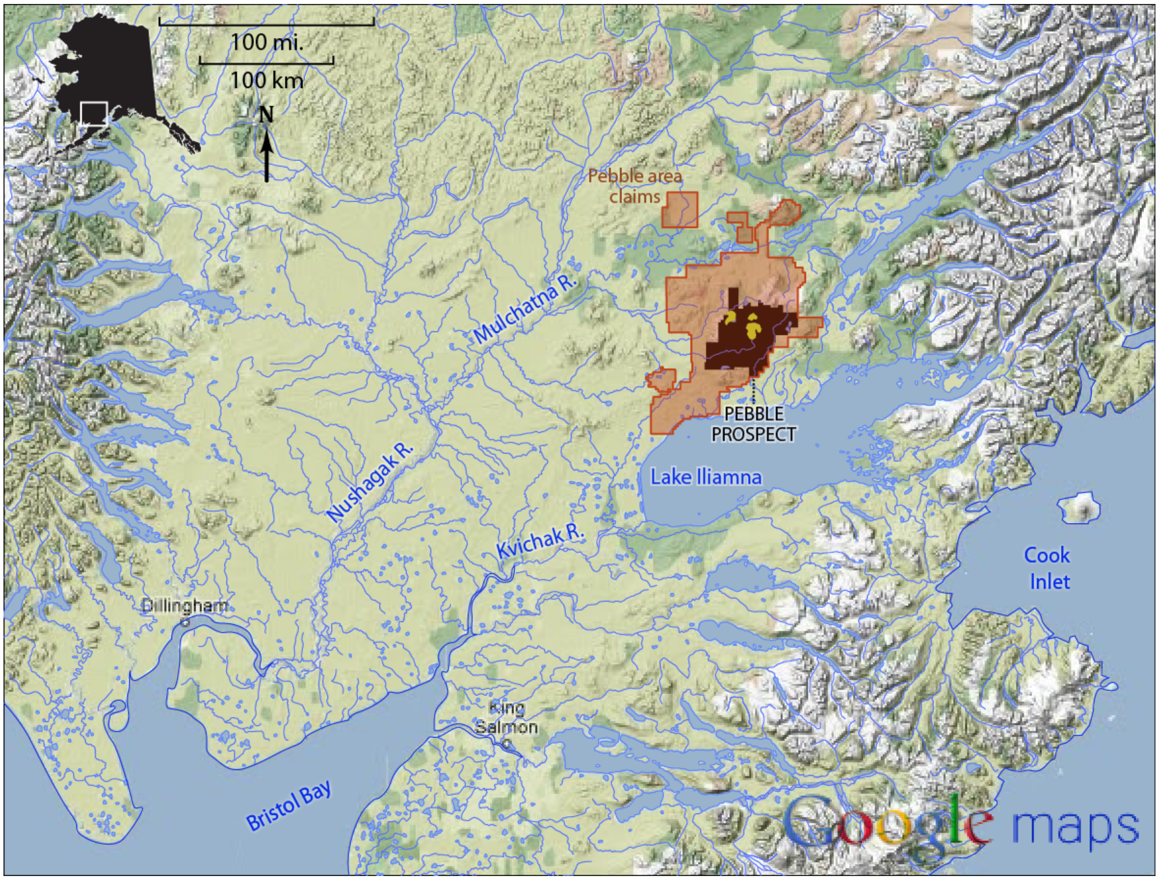

Figure 1. The Nushagak and Kvichak River drainages relative to State mine leases as of 2011(red). The Pebble prospect is located within the greater lease area (black).

Because of the importance of Bristol Bay salmon to fisheries stakeholders, a scientific critique of escapement methods based on standard peer review criteria was conducted (ESA 2012). Review focused on use of statistically rigorous, transparent methods, reproducibility of methods, the degree to which conclusions are supported, and general scientific soundness (ESA 2012).

Escapement Methods

Salmon spawning escapement was estimated for three main stem rivers draining the Pebble prospect: the North Fork Koktuli River, the South Fork Koktuli River and Upper Talarik Creek. Surveys included a few select tributaries but the majority of tributaries were not surveyed (see EBD Figures 15.1-21, 15.1-50, 15.1-79). Adult salmon were identified and counted from a helicopter during 2004-2008; surveys were intermittent as number of surveys, dates of surveys, and length of river surveyed varied among years (Appendix I; and see NDM 2005, McLarnon 2007, PLP 2012).

Total escapement from aerial index counts was estimated by expanding intermittent aerial counts with area-under-the-curve (AUC) methods, the Trapezoidal and Maximum Likelihood Models (Appendix I; and see NDM 2005, McLarnon 2007, Parsons and Skalski 2009, 2010). Two parameters critical to AUC models are:

1. estimated survey-life (i.e., number of days a salmon remains in the survey area), and;

2. observer efficiency (i.e., how accurately observers identify and count salmon (Appendix I).

Detailed methods for AUC total escapement estimates are not presented.

A mean index count (MIC) based on Holt and Cox (2008) was used to estimate relative escapement. Detailed methods are not provided (Appendix I) but use of methods described by Holt and Cox (2008) are cited. Accuracy and precision for the MIC are unknown (Holt and Cox 2008). MIC estimates for the North and South Fork Koktuli River, Upper Talarik Creek and select tributaries were compared to ADFG total escapement estimates for the Nushagak and Kvichak Rivers (Appendix I).

Escapement Results

Total annual salmon escapement estimates based on AUC models are not presented in the EBD. Select aerial index counts are presented as illustrated in Figure 15.1-93 for Upper Talarik Creek, Kvichak River watershed (PLP 2012). Exact number of surveys conducted annually, species counts for each survey and data selected to create graphs are not detailed in the EBD.

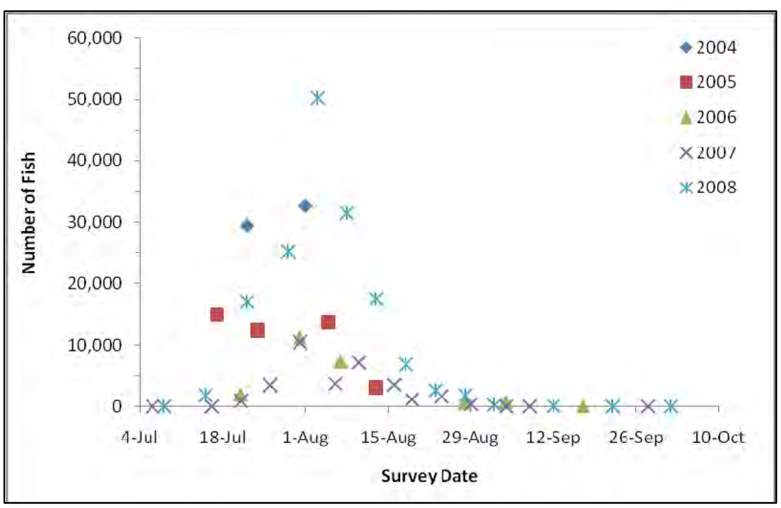

FIGURE 15.1-93
Index Counts of Adult Sockeye Salmon from Aerial Surveys in the Upper Talarik Watershed, Excluding Upper Talarik Tributary 1.60
Note: Data presented includes only those used in the mean index count analysis.

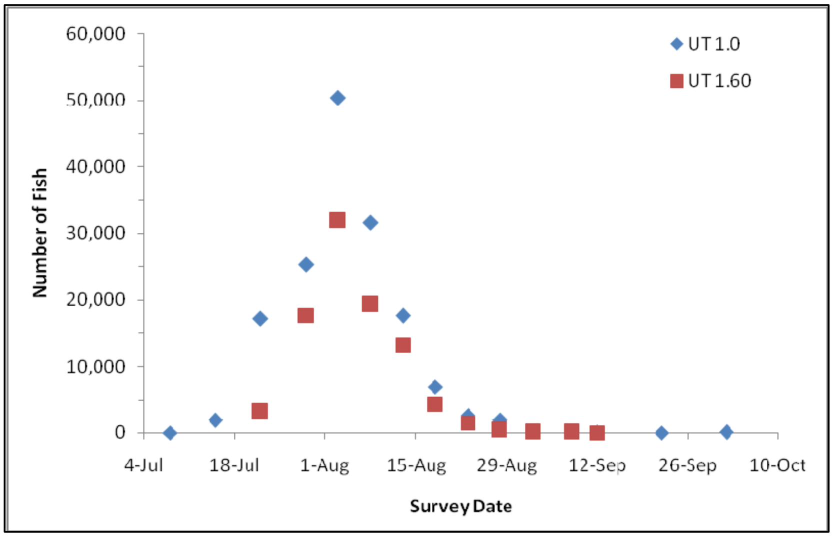

FIGURE 15.1-95
Index Counts of Adult Sockeye Salmon in the Upper Talarik Mainstem and Upper Talarik Tributary 1.60 from 2008 Aerial Surveys

Notes:

The Upper Talarik Mainstem (UT 1.0) index survey area includes Upper Talarik Tributary 1.190 and Upper Talarik Tributary 1.350.

Data presented includes only those used in the mean index count analysis.

One graph of select count data for Upper Talarik Creek and tributary (UT 1.60) illustrates total aerial escapement counts for a study river (Figure 15.1-95; PLP 2012); similar graphics are not provided for other study years and rivers. Criteria for inclusion or exclusion of data from the graphics are unclear, but as noted below the figure title some data are excluded. Reproduction of results based on the EBD (Appendix I) is not feasible.

Figure 15.1-95 (PLP 2012) suggests over 80,000 sockeye salmon were counted during one aerial survey (2 August) in Upper Talarik Creek and tributary 1.60. This estimate combined with remaining aerial count data suggest that over 100,000 spawning sockeye salmon were counted in Upper Talarik Creek in 2008. A similar data graph by river that includes all years and all species is not in the EBD but would provide readers a valuable snapshot of total aerial survey count results.

Mean Index Count (MIC) results are presented graphically as illustrated in Figure 15.1-96 (PLP 2012). It is unclear from results if methods used to calculate the MIC in the figure below are based on Holt and Cox (2008) or are an average of counts presented in the previous Figure 15.1-95. If not based on Holt and Cox (2008) then means are an average of all aerial counts made in 2008 and potentially include zero counts. Exact data selected for means and calculation methods are unclear and results are not reproducible as presented.

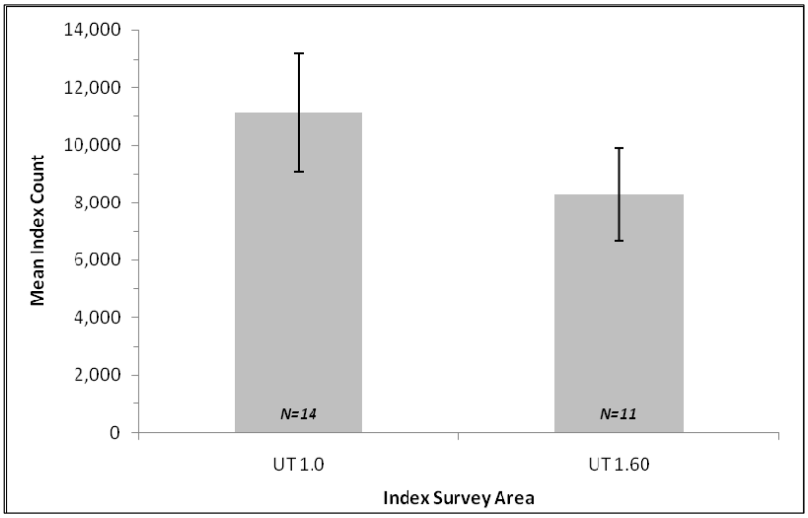

FIGURE 15.1-96
Sockeye Salmon Mean Index Counts (±1 Standard Error) in the Upper Talarik Mainstem 1.0 and Upper Talarik Tributary 1.60 from 2008 Aerial Surveys

Notes:

The Upper Talarik Mainstem (UT 1.0) index survey area includes Upper Talarik Tributary 1.190 and Upper Talarik Tributary 1.350.

N is the number of surveys included in the index analysis.

UT = Upper Talarik Creek

Annual aerial count data are also presented by river study section and species for 2008 only (Figure B.12-15 from PLP 2012). Upper Talarik Creek was divided into seven sections for study (A-G see map Appendix II). In section A, aerial survey results for sockeye salmon on 2 August 2008 indicated: about 32,000 spawners, 100 carcasses, over 500 migrating, 10,000 milling and about 50 post spawning sockeye were observed. Such information could potentially be useful in determining which river sections support high salmon spawning densities and high quality spawning habitat. However, bias and precision estimates for aerial counts are required prior to such application.

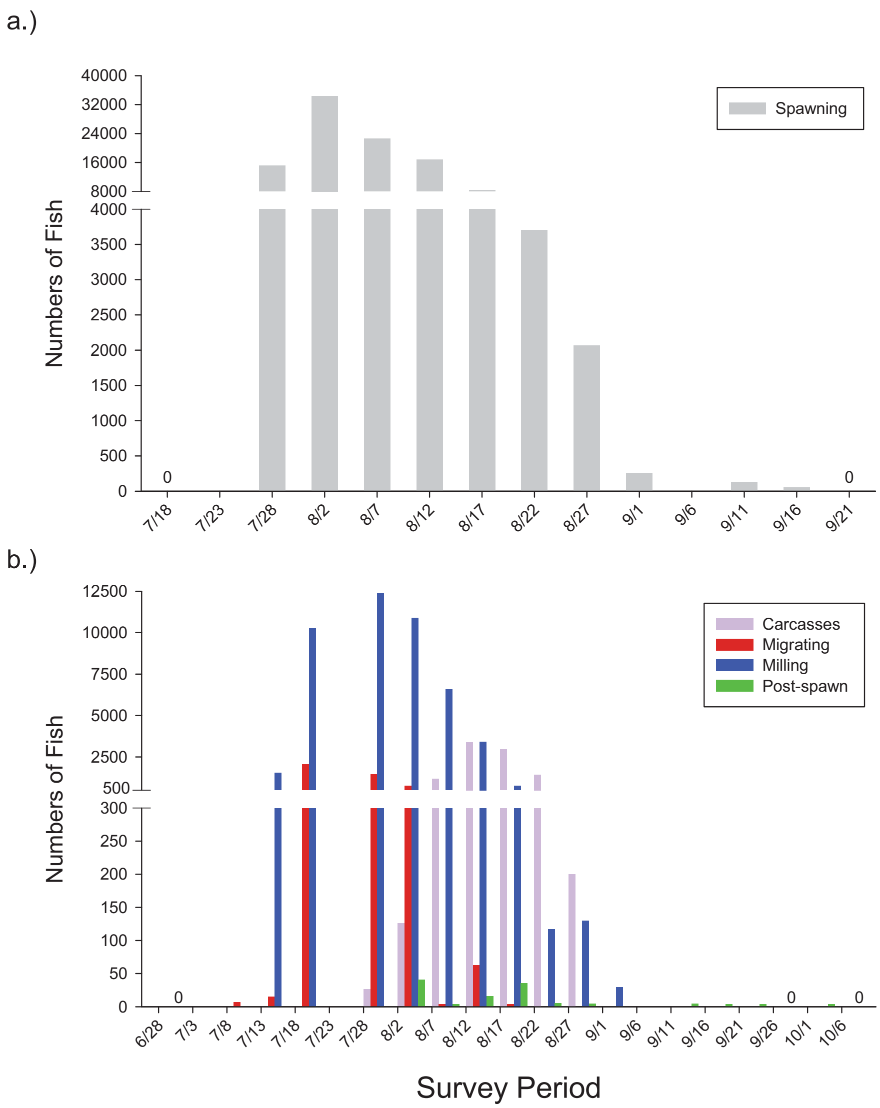

Figure B.12-15.
Observations of sockeye salmon during 2008 aerial surveys in UT-A. a.) Number of sockeye salmon spawning. b.) Number of sockeye salmon observed in spawning related behaviors.

Mean Index Counts (MIC) (2007) are presented for all years in conjunction with total escapement counts made from passage counts by ADFG in both graphic (e.g., Figure 15.1-94) and tabular format (Table 15.1-41). Here, Upper Talarik Creek MICs and Kvichak River tower counts are used as an example to illustrate discussion. Both the graph and table compare the MIC with unknown bias and variance to total escapement estimates that are unbiased and precise; such a comparison is not scientifically valid and is potentially deceptive. The MIC gives a statistically unreliable relative escapement estimate (Parsons and Skalski 2010). In contrast ADFG passage counts provide a total escapement estimate within ±10% of the actual total number of spawning salmon 95% of the time for a river watershed.

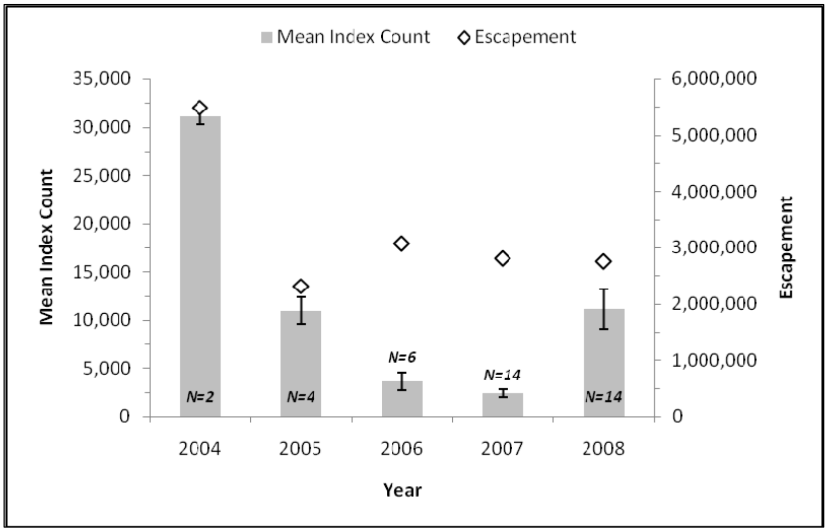

FIGURE 15.1-94
Sockeye Salmon Annual Mean Index Counts (±1 Standard Error) in the Upper Talarik Watershed (Excluding Upper Talarik Tributary 1.60) and Kvichak River Spawning Escapement

Note: *N* is the number of surveys included in the index analysis.
Source: Escapement estimates were taken from Baker et al. (2009), Appendix A5.

TABLE 15.1-41
Adult Salmon Statistics for the Naknek-Kvichak District, Kvichak River, and Upper Talarik Watershed

Species	Year	District Total Inshore Run [a]	District Commercial Catch [a]	Kvichak River Escapement [b]	UT Mean Index Count [c]	*N* (UT)
Chinook salmon	2004	--	1,360	--	178 (±94.5)	2
	2005	--	1,377	--	60 (±20.5)	3
	2006	--	2,333	--	49 (±25.2)	3
	2007	--	1,484	--	67 (±19.2)	9
	2008	--	1,344	--	28 (±12.4)	8
	5-Year Avg	--	1,580	--	76	--
Chum salmon	2004	--	29,972	--	--	0
	2005	--	204,777	--	--	1
	2006	--	457,855	--	13 (±2)	2
	2007	--	383,927	--	5 (±0.9)	8
	2008	--	237,260	--	17 (±5.6)	7
	5-Year Avg	--	262,758	--	12	--
Coho salmon	2004	--	2,142	--	1,143 (±689.6)	4
	2005	--	3,314	--	--	0
	2006	--	5,163	--	4,363 (±1,128.3)	3
	2007	--	2,180	--	1,773 (±589.5)	9
	2008	--	7,059	--	1,598 (±472.8)	14
	5-Year Avg	--	3,972	--	2,219	--
Sockeye salmon	2004	15,066,178	4,715,070	5,500,000	31,088 (±1,614)	2
	2005	15,984,566	6,706,386	2,320,000	10,981 (±2,698.7)	4
	2006	13,945,960	7,153,750	3,068,000	3,652 (±1,868.4)	6
	2007	17,244,437	9,022,511	2,810,000	2,362 (±845.4)	14
	2008	17,792,948	10,381,844	2,758,000	11,120 (±4,130.9)	14
	5-Year Avg	16,006,818	7,595,912	3,291,200	11,841	--

Notes:
a. Data taken from Morstad et al. (2010), Appendix A18. Total inshore run for sockeye salmon includes commercial catch and escapement.
b. Data taken from Baker et al. (2009), Appendix A5.
c. UT mean index count excludes data from UT 1.60.
N = sample size UT = Upper Talarik Creek

Discussion

Issues with Escapement Methods

1. Accuracy and Precision: Daily adult salmon passage counts past counting towers, sonar sites, and weirs are considered the most accurate and precise escapement estimation methods and are typically used where sockeye salmon are the most abundant salmon species, including Bristol Bay (Cousens et al. 1982, Hilborn et al. 1999, Anderson 2000, Holmes et al 2006, Woody 2007, Reynolds et al. 2007, Zimmerman and Zabkar 2007, Parsons and Skalski 2009, 2010). In contrast, intermittent aerial survey counts are considered one of the least accurate and precise escapement estimation methods due to issues in estimating bias and precision. These methods are typically used for relative abundance estimates of pink salmon in large remote areas such as Prince William Sound, Alaska (Evzerov 1981, Neilson and Geen 1981, Cousens et al. 1982, Shardlow et al. 1987, Perrin and Irvine 1990, Hill 1997, Bue et al. 1998, Hilborn et al. 1998, Jones et al. 1998, Jones et al. 2007, Parsons and Skalski 2009 and 2010).

   Many factors introduce bias (over or undercounting of salmon) into aerial escapement counts, such as: aerial survey date, time, frequency and length; water clarity, color and depth; weather; glare; observer experience and training; stream morphology; vegetation cover; undercut banks; fish species, run timing, and density (Bevan 1961, Cousens et al. 1982, Shardlow et al. 1987, Perrin and Irvine 1990, Hill 1997, Bue et al. 1998, Parsons and Skalski 2009 and 2010). The bias is generally negative (i.e., fish are undercounted) (Cousens et al. 1982, Daum et al. 1992, Rogers 1984, Jones et al. 2007). Because EBD aerial surveys did not include most tributaries and because salmon spawn in small tributaries, this would further bias escapement counts toward underestimates.

   Relative to AUC models that estimate total escapement, if salmon survey-life and observer efficiency are not determined, estimates are considered unreliable (Perrin and Irvine 1990, Bue et al. 1998, Parsons and Skalski 2009 and 2010). A recent review of AUC methods by Parsons and Skalski (2009 and 2010) indicates the Trapezoidal method can provide a fair estimate of total escapement if survey life and observer efficiency are determined and assumptions are met but they recommend against use of the Maximum Likelihood AUC method.

2. Salmon survey-life and observer efficiency: methods indicate both parameters were calculated annually but no details are provided. Logistical issues are cited as preventing precise determination of both survey-life and observer efficiency (Appendix I).

3. Mean Index Counts (MIC): This method does not provide an estimate of total escapement; the MIC does provide a *relative* index of abundance. It is *relative* because there is no knowledge of the proportion of the escapement not counted (e.g., due to problems of detection, survey conditions, differences among observers, etc.).

The MIC assumes observer efficiency is constant; an untenable assumption based on the literature (Bevan 1961, Evzerov 1981, Neilson and Geen 1981, Cousens et al. 1982, Shardlow et al. 1987, Jones et al. 1998, Jones et al. 2007, Parsons and Skalski 2009, 2010). Without a reliable estimate of each year's 'relative' proportion MIC estimates do not allow reliable estimation of long-term trends or changes in salmon escapement (Skalski 2009 and 2010).

A scientific literature search (Web of Science) indicates the Mean Index Count is a non-standard "indexing" method that was tested once on remote British Columbia coho salmon populations to detect a 30% decline over a 10-year period (Holt and Cox 2008). The MIC has not been evaluated for application on multi-species systems. Recommended MIC methods include maintaining a constant number of days between surveys among years and clustering surveys around historical peak dates when ≤5 surveys are conducted annually (Holt and Cox 2008). Historic information on escapements is lacking for systems draining Pebble, peak escapement dates are unknown, and annual surveys for the EBD had fewer than 5 surveys for multiple species and years.

4. General comments: detailed reproducible methods are not provided in the EBD (Appendix I). Exact model parameters, assumptions, data selection criteria, issues relative to estimating survey-life and observer efficiency, and analysis techniques are lacking for total escapement and the MIC estimates.

Issues with Escapement Results

1. Total escapement is not presented in the EBD but is essential for evaluating impact of potential mining alternatives on salmon productivity. Although EBD methods (Appendix I) and historic information (Appendix III, NDM 2005, McLarnon 2006 and 2007) indicate that observer efficiency and survey-life were estimated, the EBD (Appendix I) states estimates were inadequate and therefore AUC estimates were not determined. Details on issues encountered that prevented AUC estimates should be provided and evaluated to determine if issues can be sufficiently overcome to estimate total escapement.

2. Results of all aerial surveys are not precisely detailed by graphs alone. A companion table detailing results of each survey, by date, river and species would provide a clearer picture of total count results. Data selected and selection criteria for inclusion in graphs and tables should be detailed.

3. MIC results are unreliable and should not be used to characterize baseline multi-species salmon escapement. Tables presenting MIC estimates in conjunction with total salmon escapements made with known accuracy and precision are deceptive as they imply few salmon spawn in the study area.

Conclusions

> "If an estimate is inaccurate, i.e. biased, it does not measure the desired quantity and is therefore deceptive. If an estimate is accurate but brings with it great uncertainty, i.e., is highly variable, it is similarly useless for management purposes." Parsons and Skalski (2010).

Even though a long history of statistically rigorous transparent and respected methods for estimating absolute or total salmon escapement on large Alaskan rivers exist (e.g., towers, sonar, weirs; Anderson 2000, Woody 2007, Baker et al. 2009, Brazil and Buck 2011, Parsons and Skalski 2010) these methods were not employed to gather baseline escapement data for three relatively small rivers. Instead, one of the least rigorous escapement estimate methods, aerial counts, was used which only provides a *relative* index of abundance. (Bevan 1961, Evzerov 1981, Neilson and Geen 1981, Cousens et al. 1982, Shardlow et al. 1987, Jones et al. 1998, Jones et al. 2007, Parsons and Skalski 2009, 2010). Aerial counts are *relative* because there is no knowledge of the proportion of the escapement not counted (e.g., due to problems of detection, survey conditions, differences among observers, etc.). Without a reliable estimate of each year's 'relative' proportion such estimates do not allow reliable estimation of trends or total number of salmon potentially impacted by different mining alternatives (Parsons and Skalski 2009 and 2010). Aerial surveys should be discontinued and replaced with standard passage counts; accuracy and precision should be determined.

Total escapement estimates using AUC methods are not presented in the EBD. AUC estimates for total escapement (all salmon species) estimated during 2004 – 2007 indicate total escapement for surveyed streams may range from 42,610 to 164,620 (NDM 2005, McLarnon 2006, McLarnon 2007), but data are not in the EBD. Compiled AUC Trapezoidal estimates from agency meetings indicate total escapement of all salmon species in the study area may range from (Appendix III) which, based on aerial count data alone, appear to provide more realistic total escapement estimates than available currently. Because only aerial counts are available for portions of these systems, issues with accuracy, bias, observer efficiency and survey life should be evaluated to determine if and how statistical deficiencies can be overcome such that the AUC Trapezoidal model can be applied and total escapement estimated.

The relative index of escapement provided by the MIC is unreliable. The MIC has unknown bias and unknown uncertainty (Table 4, Holt and Cox 2008). These estimates assume observer efficiency or fish detection rate is approximately constant across years, observers and surveys; both EBD methodology (PLP 2012) and the scientific literature show this assumption is untenable (Perrin and Irvine 1990, Bue et al. 1998a, Parsons and Skalski 2009 and 2010). In short, the MIC does not provide accurate, reliable estimates of spawning salmon abundance. The single peer-reviewed publication on the MIC describes it as a "cost effective" escapement monitoring method (Holt and Cox 2008) and specifically points out the extensive historical information required in order to trust the method as a reliable means of monitoring change; this information is not available for the systems under question. The MIC method has only been tested once in an effort to detect a 30% decline in coho salmon populations of British Columbia and has not been evaluated for multi-species systems.

Recommendations

1. Total Escapement Estimates: AUC total escapement estimates for the Trapezoidal model (Bue et al. 1998, Hilborn 1999, Parsons and Skalski 2010) should be evaluated to determine if total escapement can be estimated using aerial survey data for 2004-2008. Observer efficiency (e.g., Bue et al. 1998, Parsons and Skalski 2010) and survey life (e.g., Korman Shardlow et al. 2007) should be determined and model assumptions met. AUC methods can provide a "fair" total escapement estimate; currently none is available.

2. All escapement count data including date of survey, length of survey, counts by species and river should be provided in a single table to permit rapid review of aerial count details.

3. Aerial escapement estimates should be discontinued and passage counts initiated to estimate total escapement using statistically reliable methods (weirs, towers, sonar). Control or reference sites outside project zone of influence should also be established and monitored concurrently to permit distinguishing between future development impacts and impacts from natural variation.

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Appendix I. Pebble Limited Partnership Environmental Baseline Document, Salmon Escapement Methods

From: APPENDIX E. Consolidated Study Program Salmon pages 11-24 to 11-25.
And Chapter 15. Fish and Aquatic Invertebrates Bristol Bay Drainages pages 15.1-13 to 15.1-15. Pebble Limited Partnership Environmental Baseline Document (2012).

Appendix E. 11-24-11-25.

11.4.2.5 Salmon Escapement Surveys

Salmon escapement surveys were initiated in 2004 and continued through 2008. Aerial surveys were used to quantify spawning salmon throughout the entire lengths of the mainstem NFK, SFK, and UT, and in selected tributaries in the study area, including Big Wiggly Lake on NFK tributary 1.240 (Figure 11-6). The primary objectives of the salmon escapement study were as follows:

- Document spatial and temporal distribution of anadromous salmon spawning in the mine study area.
- Obtain estimates of salmon escapement.

Survey timing and frequency varied among years (Table 11-10). Surveys typically ranged from early July through early to mid-October. In 2008, the survey period was extended until zero fish was observed (i.e., until mid-November). Because of time and weather constraints as well as helicopter availability, 2 to 3 days were typically required to cover the entire survey area in the NFK, SFK, and UT watersheds. As the escapement study progressed over the years, refinements were made to survey methods. including an increased total number of surveys flown and shorter duration between survey flights (Table 11-10).

Despite differences in survey timing among sampling years, methods used to conduct individual surveys were generally consistent among years. Surveys were conducted from a low-flying helicopter at an altitude of 100 to 200 ft (30.5 to 61 m) and at a ground speed of 5 to 20 mi/h (8 to 32 km/h). In 2004 through 2007, two qualified observers conducted each survey so that fish counts made by the first observer could be recorded by a secondary observer present at the time of the survey; field data were recorded in field notebooks and data sheets and entered into an electronic database. In 2008, a single qualified observer used a handheld digital voice recorder to record survey data. Survey data were then transcribed onto data sheets for entry into an electronic database format. Polarized glasses were used by observers to enhance visibility. Observed adult salmon were enumerated by species through direct counts of individual adult fish or estimated cluster counts (e.g., 50, 100, 500, 1,000). Estimated cluster counts were made when large numbers of fish were in concentrated areas and individual counts were not feasible or possible. Fish counts were also estimated when counts of individual fish were impaired by environmental conditions (e.g., weather, turbidity, glare). Carcasses observed during surveys were enumerated by species. Environmental conditions during surveys were assessed using qualitative indices. Recorded qualitative environmental variables include weather, sun angle, glare, flow volume and depth, turbidity, stream bottom color, aquatic vegetation and debris, overhanging vegetation, ice cover, and surveyor fatigue. Using a handheld GPS unit, waypoints were recorded to document the extent of each survey, areas of concentrated fish spawning, the upstream extent of salmon, and areas where environmental factors affected the counting process. Additional notes were recorded to describe any other conditions affecting the surveyors' abilities to enumerate fish, and to document any deviations from the schedule or changes to the methodology.

Methodologies for estimating observer efficiency were also utilized. Observer efficiency estimates are derived through comparisons between the primary observer's counts and those made by a second observer. For the 2004 through 2007 aerial surveys, the two observers counted fish simultaneously. Thirteen calibration reaches were defined for the 2004 through 2007 surveys, with three to six reaches per drainage. In 2008, video recordings of selected calibration reaches were made immediately following the primary observer's initial survey, and videos were later reviewed by a second observer on a high-definition television. In late June 2008, six calibration reaches were delineated in each watershed and marked with survey flagging. However, these established calibration reaches were replaced by roving calibration reaches in mid-July 2008, because the pre-established reaches typically lacked fish densities sufficient for calibrating observer efficiency. With roving calibration reaches, the primary observer selected different reaches in each stream for video filming. A stratified approach was used to select calibration reaches representative of different stream and survey conditions (e.g., wide stream with little cover; heavily vegetated stream) so that calibration coefficients could be adjusted to survey conditions, if necessary. GPS waypoints describing the upstream and downstream extent of all 2004 through 2008 calibration events were recorded.

Escapement was estimated using the area-under-the-curve (AUC) method. According to this method, salmon counts from periodic surveys are used to generate total escapement by fitting a curve of the counts over time, integrating the area under the curve to derive a total number of fish days, and dividing this total by the mean number of days fish are present in the stream. AUC estimates are a function of the number of fish that move into an area, the time fish remain alive in that area, and the accuracy of the counts as determined by observer efficiency during the counting surveys. Two AUC models were used to estimate escapement from fish counts. The Trapezoidal Model (Neilson and Geen, 1981; Bue et al., 1998) has been used to estimate escapement with aerial fish counts since 1981. This model uses a linear interpolation to estimate fish counts in reaches where survey data are missed because of weather or logistical limitation. The second model, the Maximum Likelihood Estimation (MLE) model (Hilborn et al., 1999), uses temporal autocorrelation of counts to generate a modeled distribution of daily abundance that is compared to period survey counts; this model relies upon independently derived estimates of mean survival time.

Site-specific residence times were estimated based on 4 years of adult salmon migration and carcass observations. In addition, separate AUC estimates were computed using literature-derived values. Stream residence time has been shown to vary within a stream and spawning season as well as between streams and years (Perrin and Irvine, 1990; Fried et al., 1998; Lady and Skalski, 1998; Manske and Schwarz, 1999). Thus, estimates were bracketed using low and high literature values for each species when available.

Interpolations were made for the 2004 through 2007 data sets when the first or last survey counts were not zero. The assumptions of the trapezoidal model are (1) the fish observed during the first survey entered the stream one survey life earlier, (2) the fish observed during the last survey were out of the system within one survey life after the last survey, and (3) no additional fish entered the study area. For the statistical model, it was assumed that (1) no fish had entered the survey area before July 1, and (2) no fish remained in the survey area one survey life after the last survey.

From Pebble Project Environmental Baseline Document 2004 through 2008. Chapter 15. Fish and Aquatic Invertebrates Bristol Bay Drainages. pages 15.1-13 to 15.1-15.

Adult Salmon Surveys

Surveys to estimate the number of adult salmon spawning within the study area were initiated in 2004 and continued annually through 2008. These surveys were designed to document the spatial and temporal distribution of anadromous salmon returning to and spawning in the NFK, SFK, and UT watersheds, and to obtain estimates of spawning salmon abundance through direct observation. For this effort, aerial helicopter surveys were used to quantify spawning salmon throughout the entire lengths of the mainstem NFK, SFK, and UT, and in selected tributaries (Photo 15.1-4). The upper KR mainstem and Big Wiggly Lake, which is located on Tributary NFK 1.240, were also targeted for aerial surveys.

Differences in survey timing and frequency occurred among sampling years. For example, 2004 was the first year of baseline studies and seven aerial surveys were completed with a survey frequency of every 14 to 22 days. In contrast, surveys were conducted every 5 days in 2008 for 26 completed surveys. Otherwise, survey methods used were generally consistent among years. Surveys typically were conducted from early July through October or November to capture the range of dates adult Chinook, chum, coho, and sockeye salmon were present in the study area. Adult salmon were enumerated by species, and environmental conditions occurring during the surveys (e.g., weather, sun angle, glare, flow volume and depth, turbidity, stream bottom color, etc.) were recorded. A handheld global positioning system (GPS) unit was used to record the extent of each survey, and to mark areas of concentrated fish spawning, the upstream extent of salmon, and areas where environmental factors (e.g., ice cover, glare, etc.) may have affected the counting process. Due to time and weather constraints, as well as helicopter availability, 2 to 3 days were typically required to cover the entire study area for each survey. In addition, aerial redd surveys were also conducted in 2004, 2005, and 2007. Redd locations were documented using a hand-held GPS unit.

Fish counts from aerial surveys are commonly used to estimate escapement of Pacific salmon species by watershed and year. Two common methods used for estimating salmon escapement are the area-under-the-curve (AUC) Trapezoidal Model (Neilson and Geen, 1981; Bue et al., 1998) and the Maximum Likelihood Estimation Model (Hilborn et al., 1999). Both of these models require assumptions about year- and stream-specific survey life and/or observer efficiency parameters. During the 2004 through 2008 study period, several attempts were made at determining site-specific values for survey life and observer efficiency. These attempts were unsuccessful at developing reliable estimates due to logistical constraints, such as low recovery of tagged fish on spawning grounds and physical stream conditions that affected the visibility of fish on reference videos. Without reliable estimates of observer efficiency and survey life, the utility of current escapement models is diminished (Holt and Cox, 2008). Furthermore, Holt and Cox (2008) present evidence that using the annual mean of survey counts is as good as, or better than, visual escapement models at illuminating trends in populations even when surveys have random spacing and high variability in frequency from year to year. For these reasons, a mean index count analysis, rather than an escapement analysis, was used to evaluate adult salmon abundance over the study period and among watersheds.

Index counts refer to the number of adult salmon observed on a given survey date. Annual mean index counts were calculated for each species by determining the mean of the index counts across the number of survey dates on which a species was observed. The subset of survey data included in the mean index count analysis was selected to allow for comparison of species-specific counts across watersheds and years. Thus, index counts from river reaches that were most consistently surveyed over the 5-year study period were used in the analysis. In order to maintain rigor in the analysis, it was also important to maximize the number of surveys included therein. Several surveys each year covered extended stream lengths and data within could not be parsed out by location; therefore, some variation in endpoints was allowed when selecting surveys for index counts. Surveys included by watershed are listed below.

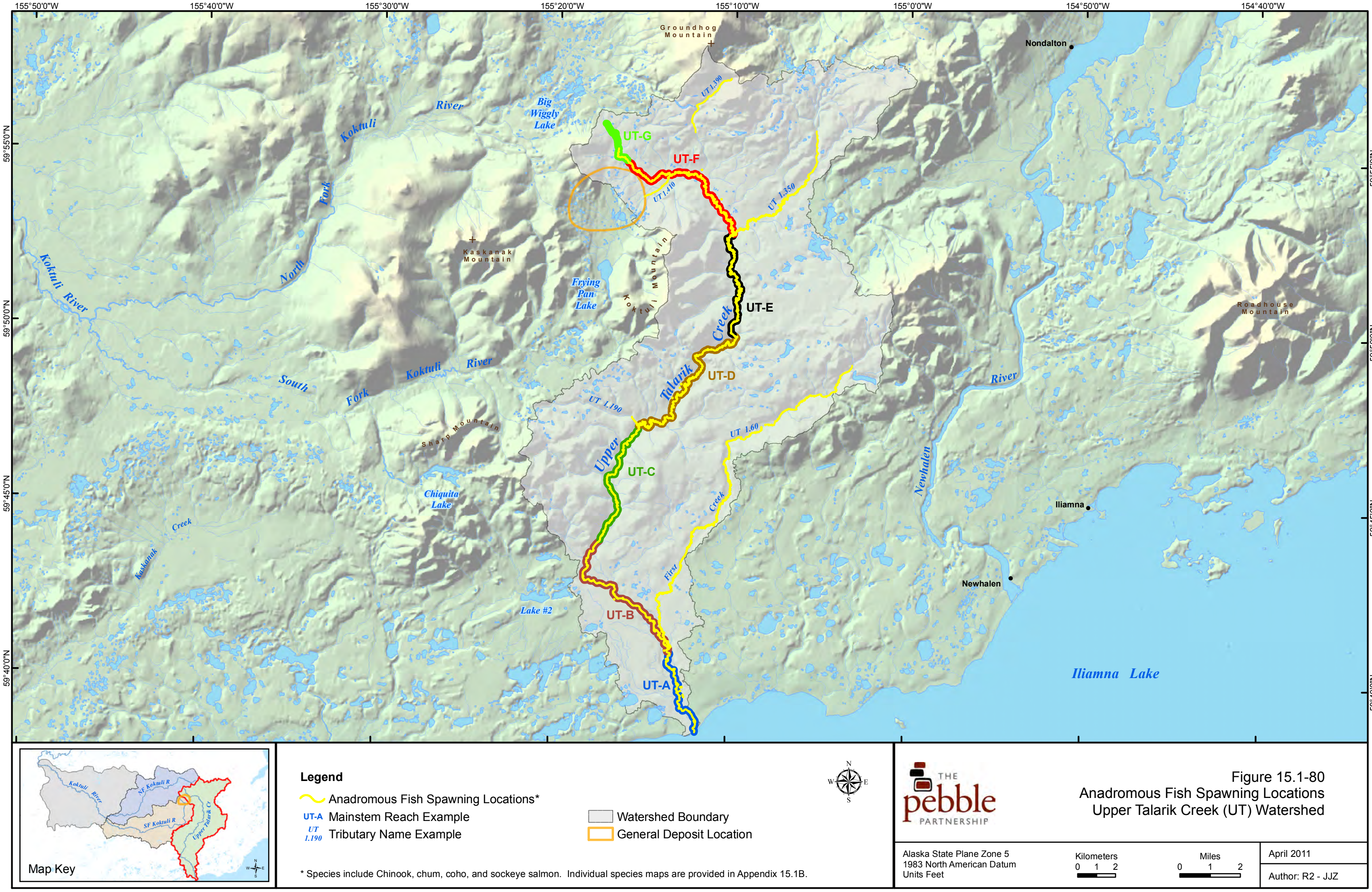
- NFK—61 complete surveys that started at the confluence with the Koktuli River and ended near Big Wiggly Lake or at River Mile (RM) 34.78 (River Kilometer [RK] 55.98)
- SFK—67 complete surveys that started at the confluence with the Koktuli River and ended at the intermittent reach or at Frying Pan Lake
- UT—51 complete surveys that started at the mouth of the UT and ended at the confluence of Tributary 1.350 or at the headwaters

Inclusion of surveys with varied endpoints allowed incorporation of fish counts from upper reaches in all three watersheds, and although these data are diminished by comparison to overall counts, they add important information—especially for coho and sockeye salmon.

In addition to the mean index count analysis, an analysis of the spatial distribution and abundance of spawning salmon within each of the three major watersheds was conducted. Raw fish counts from 2008 surveys were used for this spawning distribution analysis, because spawning salmon locations were documented within each of the 18 pre-designated reaches in the NFK, SFK, and UT watersheds starting that year. Reach-specific totals and mean numbers of spawning salmon for all survey dates were calculated for each species and were compared across reaches. All survey data collected in 2008 were included in the analysis.

Lastly, for each species, the 2004 through 2008 mean index counts were used to provide a first-order approximation of the relationship between counts in the NFK, SFK, and UT, and ADF&G's Bristol Bay fisheries statistics. Specifically, the Bristol Bay fisheries statistics considered were total inshore run estimates and commercial catch statistics for the Nushagak and Naknek-Kvichak districts (Morstad et al., 2010) and salmon escapement estimates for the Nushagak and Kvichak rivers (Baker et al., 2009). Although not directly comparable, the relative magnitude of the difference between the annual mean index counts and the Bristol Bay fisheries statistics will provide an indication of relative scale of the NFK, SFK, and UT runs compared to the runs into the larger river systems and respective commercial fishery districts.

Appendix II. Map illustrating distribution of Upper Talarik Creek study sections used From PLP (2012).



Appendix III. Summary of aerial escapement information (NDM 2005, McLarnon 2006, McLarnon 2007, PLP 2012). Total escapement estimate is based on the Trapezoidal method of Area-Under-the –Curve estimates. Highlighted numbers indicate a difference in the number of surveys conducted and number of surveys ultimately used to calculate MIC estimates in the EBD (PLP 2012). Relative MIC estimates are purportedly based on methods of Holt and Cox (2008). Observer efficiency is how accurately fish were counted, survey life is how long salmon remained in study area. Likely range is the range within which total salmon escapement for surveyed areas falls.

River & Species	Year	No. of Surveys	Observer Efficiency	Survey life	Total Escapement Estimate (Trapezoidal)	Likely Range 2006	Likely Range 2007	Relative Escapement Mean Index Count	Standard Error	No. surveys used for EBD MIC
South Fork Koktuli	2004	3	0.8	15	7,265	3,400 – 13,900	4,000 – 10,800	2,155	321.5	3
Chinook salmon	2005	7	0.8	15	3,243	1,700 – 6,000	2,000 – 4,700	789	317.3	4
	2006	8	0.8	15	978		700 – 2,400	251	76.5	5
	2007				501			148	47.4	8
	2008							213	79.4	9
Sockeye Salmon	2004	3	0.8	10	9,295	3,800 – 14,800	4,400 – 11,500	1454	155.5	2 and 3
	2005	8	0.8	10	6,791	2,500 – 10,500	3,000 – 8,000	1019	387.5	5
	2006	10	0.8	10	9,877		3,200 – 17,900	1153	396.2	8
	2007				11,753			1693	455.3	11
	2008							1791	627.1	13
Coho Salmon	2004	2	0.6	12	1,224	-	-	166	104.5	2
	2005	6	0.6	12	3,203	1,700 – 8,100	2,100 – 6,500	287	127.2	4
	2006	5	0.6	12	4,982		3,500 – 8,900	478	457.8	3
	2007				1,312			121	39.4	10
	2008							494	136.3	20
Chum Salmon	2004	-	-	-	-	-				-
	2005	6	0.6	12	1,613	900 – 4,800	1,000 – 3,300	225	79.1	4
	2006	8	0.6	12	2,445		1,400 – 4,900	335	114.9	7
	2007				480			71	22.5	11
	2008							353	135.4	7

Appendix III continued.

River & Species	Year	No. of Surveys	Observer Efficiency	Survey life	Total Escapement Estimate (Trapezoidal)	Likely Range 2006 [b]	Likely Range 2007 [b]	Relative Escapement Mean Index Count	Standard Error	No. surveys used for EBD MIC
North Fork Koktuli	2004	3	0.8	15	7,136	3,500-12,500	4,100 – 9,900	1838	541.6	3
Chinook salmon	2005	6	0.8	15	5,621	2,900-10,800	3,500 – 8,500	1737	599.1	4
	2006	7	0.8	15	1,700		650 – 2,600	512	123.9	4
	2007				741			213	74.8	8
	2008							157	62.1	8
Sockeye Salmon	2004	3	0.8	10	2,338	1,200-5,200	1,400 – 4,000	518	45	2
	2005	6	0.8	10	4,140	1,900-9,200	2,400 – 7,000	582	194.7	5
	2006	10	0.8	10	4,463		1,700 – 4,900	456	225.2	7
	2007				4,195			648	217.4	10
	2008							637	215.1	12
Coho Salmon	2004	4	0.6	12	1,660	300-4,900	500 – 3,100	158	78.3	3
	2005	1	-	-	- [c]	- [c]	-			0 or 1
	2006	6	0.6	12	3,454		700 – 2,950	449	260.7	4
	2007				408			43	16.3	8
	2008							478	138.6	15
Chum salmon	2004	1	-	-	- [c]	-	-			0 or 1
	2005	6	0.6	12	1,510	600-4,000	700 – 2,800	165	73.8	4
	2006	7	0.6	12	2,030		1,200 – 4,800	439	171.6	4
	2007				1,672			310	113	9
	2008							532	205.8	7

Appendix III continued.

Upper Talarik Creek	2004	2	0.6	15		- [c]		178	94.5	2
Sockeye salmon	2005	4	0.6	15	194	-	105 - 365	60	20.5	3
	2006				165		-	49	25.2	3
	2007				335			67	19.2	9
	2008							28	12.4	8
Sockeye Salmon	2004	2	0.7	10	125,000	- [c]	-	31088	1614	2
	2005	5	0.7	10	62,771	26,000-94,000	31,000 – 74,000	10981	2698.7	4
	2006	8	0.7	10	33,059		-	3652	1868.4	6
	2007	14			24,278			2362	845.4	14
	2008	14						11120	4130.9	14
Coho Salmon	2004	4	0.6	12	8,452	800-47,100	1,500 – 23,000	1143	689.6	4
	2005	4	0.6	12	6,277	-	3,000 – 9,700			0
	2006	5	0.6	12	23,467		-	4363	1128.3	3
	2007				11,654			1773	589.5	9
	2008							1598	472.8	14
Chum Salmon	2004									
	2005									
	2006	2						13	2	2
	2007	8						5	0.9	8
	2008	7						17	5.6	7