2007 Arctic Yukon Kuskokwim Sustainable Salmon Initiative Project Final Product

Alternative methods for setting escapement goals in AYK[1]

by:

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Abstract

The escapement goals and management strategies for salmon stocks in the AYK region have been the subject of considerable controversy yet are critical in the management of these resources. It is widely recognized that there are limitations to the existing methods of creating brood tables and fitting Ricker or other stock-recruitment curves to these data, given the limited information for many AYK systems. In recent years there have been a number of new initiatives for evaluation of escapement goals, including methods that formally incorporate uncertainty and risk, habitat conditions, explicit analysis of life histories, use of data other than brood tables, understanding of stock structure and biocomplexity within watersheds, and evaluation of objectives other than maximum sustained yield. This project brought together a range of experts to evaluate the utility of these new methods for determining escapement goals for AYK stocks, assemble existing data relevant to calculation of AYK escapement goals, and to try to apply the new tools to several AYK systems.

In this report, we present results from six activities. First, we provide a summary of existing data potentially useful for traditional escapement goal analyses, and a listing of all the technical reports in support of those data. In addition, CDs of the actual data are being supplied to AYK SSI staff. Second, we present a preliminary approach for assigning a metric to data quality so that data quality might be incorporated into future models. Third, we report on the reanalysis of productivity changes in three AYK salmon stocks, including three additional years of brood-year catch and escapement data. The reanalysis reinforced the conclusions from the 2004 analysis: all three stocks exhibit a strong downward, long-term trend in density-corrected recruits per spawner; and the strong year effects after correcting for both the trend and density show strong driving by some regional factor that affects all three stocks more or less synchronously. Fourth, we present a brief discussion of the potential effects of marine-derived nutrients on escapement goals. Fifth, we compare a new method of life-history-based modeling to outcomes of traditional spawner-recruit models. We find that escapement goals as determined by a life history approach are lower than escapement goals using a traditional Ricker analysis. Last, we present a preliminary overview of the kind of analysis that could eventually be useful for habitat-based estimates of spawning goals, by linking the total estimated rearing area of different types to the production rates for each habitat type.

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1 Introduction

The main goal of this pilot project was to compare the various methods currently being developed to answer escapement goal analysis questions, and to ascertain the availability of data required by those methods. The works of Daniel Goodman (Montana State University) on uncertainty and risk, Knudsen (Consulting Fisheries Scientist, Mt. Vernon, WA) on habitat, Stanford (University of Montana) on habitat, Adkison (University of Alaska) on stock performance, and Hilborn (University of Washington) on life history models are each dependent on some form of data as input for assessment. They either require empirical studies from which to derive parameters for the models, or on catch and escapement data to which they statistically fit their models to assess system productivity and establish harvest levels. During a meeting in June 2006, AYK regional managers provided advice on the availability of catch and escapement data. The meeting resulted in the identification of key river systems that could be used to compare the methods and evaluate their utility to AYK salmon management. During the course of the meeting, it was decided that the most useful outcomes of this pilot initiative would be:

1. To assemble a summary report of the availability of data and identify data quality
2. Target a subset of the available data to compare the results obtained from setting escapement goals using:
    - a) Traditional stock recruitment relationships
    - b) Life history model approach
    - c) Habitat based approach
3. To asses the value of marine derived nutrient information

It was recognized that very few of the systems in the AYK region had long time series of spawner and recruit data to meet the needs of 2a and 2b but, in cases where long time series were lacking, that there was potential for the habitat-based assessments because habitat information is being obtained from remotely sensed data. In this report, we present a summary of data availability in Section 2 ,a preliminary approach for categorizing data quality in Section 3, a re-analysis of productivity for several stocks in Section 4, a discussion of the potential for incorporating marine derived nutrient information into escapement goal analysis in Section 5, a comparison of life-history-based and traditional spawner-recruit methods for estimating escapement goals in section 6, and a preliminary description of habitat-based production assessment techniques in Section 7.

2 Data Compilation of Select Salmon Stocks in the AYK Region – B. Bue

Counts of fish identified to river system of origin for all components of a salmon return are typically the ideal data type required for estimating salmon escapement goals. This is typically not the case for salmon fisheries in Alaska where the size and location of the river drainages, and the magnitude of the individual stocks, often make it economically unrealistic to obtain counts of fish identified to river system of origin. Biologists in the AYK Region of Alaska have made significant improvements in their stock assessment programs in recent years, moving from infrequent aerial surveys for estimating spawning escapement, to more defined population assessment programs. Five of the eight river system-species combinations examined by this study use weirs or tower counts of salmon to estimate escapement and, as such, most likely have very good to excellent estimates. One system used sonar technology and most likely obtained good to very good estimates, while two of the river systems utilized run reconstruction models based on a combination of tower counts and aerial surveys to obtain fair to good estimates. Salmon from these systems are harvested in mixed-stock subsistence and commercial fisheries. While adequate estimates of the number of fish in the subsistence and commercial catches are generally obtained, stock composition estimates, when made, are usually questionable. The development of accurate and precise estimates of stock contribution to the subsistence and commercial catches for these mixed-stock fisheries would provide a significant improvement in data quality.

For this study, salmon abundance data, as well as age-sex-length (ASL) data, were collected for specific salmon species from eight river systems in the AYK area. The systems and species were Nome River chum salmon, Kwiniuk River chum salmon, Unalakleet River Chinook salmon, Anvik River chum salmon, Andreafsky River chum salmon, Chena River Chinook salmon, Kwethluk River Chinook salmon, and Kwethluk River chum salmon.

Accompanying project reports were also assembled for each system. They typically describe problems with the data set such as inoperable weirs or down sonar counters. The same information is most likely available for earlier years but in paper form and ultimately more costly to obtain. All electronic files included are identified by italics in this report.

Each River system-species combination has a directory containing the applicable information on the CD supplied. There is an ASL subdirectory in all river system-species directories except those that flow into the Yukon. There are separate directories for Yukon Chinook salmon and Yukon chum salmon. The Yukon ASL data sets were further broken down into separate district subdirectories because of limitations with the number of available rows in Excel and the number of fish in the database. In some cases the district data sets had to be broken into smaller groupings yet, typically at a year. For example, the Chinook salmon ASL data for district Y1 was broken into a file containing data for years 1990 and greater and a second file for years 1989 and lower. In addition, there are separate directories containing the chum and chinook salmon ASL data for the Kuskokwim River catches. The file *ASL_Location.xls* contains the location codes for all of the projects covered in this data collection and Table 3 (page 12) of the file

2006_Yukon_River_ASL Procedures.pdf contains all of the codes for species, project, gear type, and length type.

Nome River Chum Salmon

Nome River escapement data can be found in *Nome River Escapement.xls*. Aerial survey counts were found in Kohler et al. 2005 (p 122) and Clark 2001b. Escapement numbers came from recent weir reports Kohler and Knuepfer 2001b, Kohler and Todd 2003, and Kohler 2003 (*Kohler_&_Knuepfer_RIR3A02-13.pdf, Kohler & Todd 2003.pdf , Kohler_2003_ RIR3A03-33.pdf*).

ASL data for the Nome River is provided. No ASL data for chum salmon were found for the Nome Subdistrict.

Subsistence and commercial catch data can be found in *Menard & Bergstrom 2003.pdf* (Table 1, page 11) and the Annual Management Report for 2004 (Kohler et al. 2005, RIR 3A05-04, page 107-108; provided in paper form).

Kwiniuk River Chum Salmon

ADF&G estimated a brood table for Kwiniuk River Chum Salmon (Tab "Kwin S-R" in file *ADF&G_Kwiniuk-Tubutulik_Chum_Brood_Table.xls*). Subsistence and commercial catch numbers for the Kwiniuk River are obtained from the Moses Point commercial fishery, while subsistence catch numbers are also obtained from harvest both above and below the Kwiniuk Tower. Escapement is estimated using a tower on the Kwiniuk River. Two river systems contribute significant numbers of chum salmon to catches in the Moses Point fishery, the Kwiniuk and Tubutulik Rivers. Aerial surveys are flown almost annually on both systems from the mid 1960's. Assumptions of equal run timing and fish visibility to the aerial observer for each river system were made. A relationship was developed between the aerial observations and tower estimates for the Kwiniuk River, and this relationship was used to expand the Tubutulik River aerial observations into an escapement estimate. The proportion of the total escapement to the two rivers that could be attributed to the Kwiniuk River was then applied to the Moses Point catches to estimate the Kwiniuk component.

ASL data are provided for the Moses Point subdistrict and the Kwiniuk River.

Subsistence and commercial catch data can be found in *Menard & Bergstrom 2003.pdf* (Table 2, page 12-13) and the Annual Management Report for 2004 (Kohler et al. 2005, RIR 3A05-04, page 111; provided in paper form). These numbers are the same as those used in the ADF&G brood table.

Escapement estimates for the Kwiniuk River can be found in Appendix A1., page 36, of Kent 2006 (*Kent 2006 - fds06-22.pdf*). These numbers are the same as those used in the ADF&G brood table. Annual reports for the tower project for the years 2001-2005 are included in pdf form (*Kohler & Knuepfer 2002.pdf*, *Kohler & Todd 2003.pdf*, *Kohler 2003.pdf*, *Menard & Kent 2005 - fds05-24.pdf*, *Kent 2006 - fds06-22.pdf*). These reports provide information on the quality of the escapement estimate and how missed counts were interpolated. Previous projects reports are in paper form and can most likely be obtained if needed. A report documenting an assessment of the precision of the estimates is also included (*Hamazaki 2003.pdf*).

Unalakleet River Chinook Salmon

ADF&G is in the process of finalizing a report which evaluates the available data for Unalakleet River Chinook Salmon and recommends an escapement goal. The report is in draft form and a draft brood table is available (*ADF&G_Unalakleet_Chinook_Brood_Table.xls*). Maps of the river system are also included (*ADF&G_Unalakleet_Chinook_maps.doc*). Subsistence and commercial catches occur in both Subdistrict 5 (Shaktoolik) and 6 (Unalakleet). In addition, Chinook salmon bound for the Yukon River are most likely present. The Unalakleet River is the most popular sport fishery in the Norton Sound area. No estimates of stock contribution are available for these fisheries. Aerial surveys of portions of the drainage have been flown intermittently since 1958. A counting tower was first operational in 1972 with intermittent operation until 1996. The tower has been operated annually since. Data from a tagging study, conducted in 1997 and 1998, are presently used to estimate the proportion of the total Unalakleet River Chinook salmon escapement which passes the North River Tower.

ASL data. Unalakleet Subdistrict (6), Shaktoolik Subdistrict (5), Unalakleet escapement, and Unalakleet river testfish are included

Subsistence and commercial catch numbers can be found in the Annual Management Report for 2004 (Kohler et al. 2005, RIR 3A05-04, page 115-118; provided in paper form). Commercial catch numbers correspond with those found in the ADF&G brood table while subsistence numbers correspond until 1996. Subsistence catches from St. Michael and Stebbins have been removed from the AMR numbers (*Pers. Comm.* Jim Menard, ADF&G). Sport catch numbers can be found in DeCicco 2004 (*DeCicco_2004_Fmr04-01.pdf*) pages 46-47. Sport catch numbers correspond with those found in the ADF&G brood year file, tab “T.1-Harvest”.

North River tower counts can be found under tab “T.2-TOWER ESCP” of the ADF&G brood table spreadsheet. No tower reports in pdf were found although paper copies do exist but are not included here.

Aerial counts in the ADF&G brood table spreadsheet (tab “T.4-AERIAL NR”) correspond with those in the 2004 AMR (Kohler et al. 2005, RIR 3A05-04, page 125; provided in paper form).

The tagging study used by ADF&G to expand the North River tower count into a drainage-wide estimate of escapement (Wuttig 1999; *Wuttig_1999_fds99-10.pdf*) is included.

Andreafsky River Chum Salmon

The brood table developed by ADF&G for the Andreafsky River chum salmon population is included (*Andreafsky_Brood.xls*). The assumptions ADF&G makes regarding brood table development are included under a tab in the spreadsheet with a detailed description being presented in Clark 2001a. A great deal of run reconstruction went into the development of this table. There are 2 forks of the Andreafsky River, East and West forks. Aerial surveys have been flown intermittently on both forks since 1972 with ground-based escapement projects on the East Fork in 1981-1984 (ADF&G sonar), 1986-1988 (ADF&G tower), and 1994-present (USFWS weir). Subsistence and commercial catches come from the Yukon River District below the Andreafsky River (Districts 1) as well as the District the Andreafsky River flows into (District 2). The run of chum salmon to the Andreafsky River occurs during late June through mid-August and is designated a summer chum salmon stock.

I did not find a stock ID study that estimates Andreafsky River contribution to the Yukon River catches of summer chum salmon. The run of chum salmon to the Andreaffsky River occurs during late June through mid-August and is designated a summer chum salmon stock.

ASL data for all areas of the Yukon River are included. The Andreafsky River enters into the Yukon River in Subdistrict 2; thus the ASL data specifically for the Andreafsky River will be found in the Y2 data set.

Summer chum catches for all districts of the Yukon River can be found in the file *Yukon River Catch Data .xls* under the tab "A.18 (05)".

Project reports for the weir counts of 1997, 1998, 2001, 2002, 2003, and 2004 are included (*Tobin_Harper_1998_AFDS98-2.pdf, Tobin_Harper_1999_AFDS99-3.pdf, Zabkar_&_Harper_2003_AFDS2003-5.pdf, Gewin_&_VanHatten_2005_AFDS05-10.pdf, Gewin_2005_ AFDS05-13.pdf*).

Anvik River Chum Salmon

The brood table developed by ADF&G for the Anvik River is included (*Anvik_Brood.xls*). The assumptions ADF&G makes regarding brood table development are included under a tab in the spreadsheet with a detailed description presented in Clark and Sandone 2001. Escapement has been estimated on the Anvik River since 1972. A tower and expanded aerial survey data were used to estimate escapement from 1972-1978 and in-river sonar counts since 1979. Subsistence and commercial catches come from the Yukon River Districts below the Anvik River (Districts 1-3) as well as the District the Anvik River flows into (District 4). The run of chum salmon to the Anvik River occurs during late June and July and is designated a summer chum salmon stock.

ASL data for all areas of the Yukon River are included. The Anvik River enters into the Yukon River in Subdistrict 4a; thus the ASL data specifically for the Anvik River will be found in the Y4 data set.

Escapement numbers from 1979-2005 can be found in McEwen 2006a & 2006b (*McEwen 2006 - fds06-42.pdf*, *McEwen 2006 - fds06-43.pdf*) and correspond with the escapement estimates used in the ADF&G brood table. Escapement was estimated for 1972-1978 using a tower count and expanded aerial survey estimates. The estimates used in the ADF&G brood table are the same as those used by Clark and Sandone 2001. The methodology used for the expansion and the original estimates were not found. The tower counts are most likely available in project reports in the Anchorage ADF&G office. Figure 2 in McEwen 2006 provides a good illustration of the location of past tower projects and the present sonar project.

Catch data for summer chum for the various Yukon River districts can be found in the file *Yukon River Catch Data .xls* under the tab "A.18 (05)".

Chum salmon escapement past Pilot Station is estimated using sonar and a species apportionment program. The most recent estimation method has been in place since 2004 with the current estimates being presented in Table 2 of JTC 2006 (*JTC_2006_DRAFT_RIR3A06-034.pdf*). Clark and Sandone 2001 used the relationship between the chum salmon estimate at Pilot Station and the corresponding estimate on the Anvik River to estimate the proportion of the Yukon River run above Pilot Station going to the Anvik River, and eventually the estimated proportion of the catch which was of Anvik River origin.

Chena River Chinook Salmon

The brood table developed by ADF&G for the Chena River Chinook salmon stock is included (*ChenaSalchaBroodTables-2003.xls*). There is a tab labeled "README" that describes the construction of the table as well as a tab "DATASOURCES" with cites for the various data sources. The most recent escapement goal review is Evenson 2002 (*Evenson_2002_fm02-01.pdf*).

ASL data for Districts of the Yukon River are included.

Escapement has been estimated using both mark-recapture methods and tower counts. The most recent published escapement report (Doxey et al. 2005; *Doxey_etal_2005_fds05-65.pdf*) provides a summarization of the historic escapement estimates and aerial survey observations (Table 18, page 34). Annual project reports for the escapement studies are provided for 1992-2003 (*Doxey_etal_2005_fds05-65.pdf, Doxey - fds04-01.pdf, Stuby_2001_fds01-24.pdf, Stuby_2000_ fds00-04.pdf, Stuby_1999_ fds99-13.pdf, Stuby_&_Evenson_1998_fds98-11.pdf, Evenson_&_Stuby_1997_fds97-31.pdf, Evenson_1996_fds96-17.pdf, Evenson_1995_fds95-05.pdf, Skaugstad_1994_fds94-14.pdf, Evenson_1993_fds93-06.pdf*).

Chena River Chinook salmon are harvested in subsistence, personal use, commercial, and sport fisheries. Catch data are provided in the file *Yukon River Catch Data .xls*. Proportions of the commercial and subsistence catches in the Yukon River from the lower, middle, and upper Yukon River are presented in Table 10, page 96 of JTC 2006 (*JTC_2006_DRAFT_RIR3A06-034.pdf*).

Kwethluk River Chinook Salmon

A brood table for Kwethluk River Chinook salmon has not been developed, primarily because of the lack of a reliable method of allocating catch. Data on the numbers of Chinook salmon taken in the commercial, subsistence, and test fisheries in the Kuskokwim River can be found in the latest Kuskokwim Annual Management Report (*Kuskokwim_AMR_2003_fmr05-72.pdf*; Appendix B1 p 158) and the 2005 Subsistence Catch Report (*Subsistence_Catch_2005_fmr06-44.pdf*; Table 1 page 16). ASL data from subsistence and commercial catches, and escapement for Kwethluk River chinook salmon are included.

Compilation of data used by ADF&G to describe the escapement of Chinook salmon into the Kwethluk River can be found in *Kwethluk_River_Chinook_Salmon.xls*.

Limited aerial survey data are available for the years 1960-1989 while surveys have been conducted annually since 2002. No documentation of the number of surveys conducted annually or the weather/stream conditions during the surveys was collected by me. While this information may exist in ADF&G reports and files, I did not spend the time to retrieve it.

Weir counts are available for 1992, 2000, and 2002-2004. The weir was not operated in 2005 due to high water. Some interpolation was made for the 2002 count. Actual count 8,396. Interpolated count 8,502. Project reports for the 2000 through 2004 seasons are included in pdf form (*2000_Kwethluk_Weir_Report_00-019final.pdf*, *2001_Kwethluk_Weir_Report_00-019final.pdf*, *2002_Kwethluk_Weir_Report_00-019final.pdf*, *2003_Kwethluk_Weir_Report_00-019final.pdf*, *2004_Weir_Project 04-3012004.pdf*). Project reports include discussion of down time and interpolations used to expand for down time.

Tower counts were made in 1996 and 1997.

Kwethluk River Chum Salmon

A brood table for Kwethluk River chum salmon has not been developed, primarily because of the lack of a reliable method of allocating catch. Data on the numbers of chum salmon taken in the commercial, subsistence, and test fisheries in the Kuskokwim River can be found in the latest Kuskokwim Annual Management Report (*Kuskokwim_AMR_2003_fmr05-72.pdf*; Appendix B2 page 159) and the 2005 Subsistence Catch Report (*Subsistence_Catch_2005_fmr06-44.pdf*; Table 2 page 18). ASL data from subsistence and commercial catches, and escapement for Kwethluk River chum salmon are included.

The compilation of data used by ADF&G to describe the escapement of chum salmon into the Kwethluk River can be found in *Kwethluk_River_Chum_Salmon.xls*.

Weir counts are available for 1992, 2000, and 2002-2004. The weir was not operated in 2005 due to high water. Some interpolation was made for the 2002 count. Actual count 34,681. Interpolated count 35,854. Project reports for the 2000 through 2004 seasons are included in pdf form (*2000_Kwethluk_Weir_Report_00-019final.pdf*, *2001_Kwethluk_Weir_Report_00-*

019final.pdf, *2002_Kwethluk_Weir_Report_00-019final.pdf*, *2003_Kwethluk_Weir_Report_00-019final.pdf*, *2004_Weir_Project 04-3012004.pdf*). Project reports include discussion of down time and interpolations used to expand for down time.

Tower counts were made in 1996 and 1997.

Yukon River Fall Chum

Yukon River Fall Chum Salmon abundance data were assembled from the Alaska Department of Fish and Game as well as the U.S. Fish & Wildlife Service. I tried to collect as many of the pertinent project reports that were available in *pdf* form. These reports typically describe problems with the data set such as inoperable weirs or down sonar counters. The same information is most likely available for earlier years but in paper form and would ultimately be more costly to obtain. The Excel file *Fall Chum Escapement Reports Listing.xls* is a listing of pertinent reports provided to me by Bonnie Borba (ADF&G).

The run reconstruction developed by Eggers (2001; *Eggers_Fall_Chum_RIR3A01-10.pdf*) has been used in recent years for estimating total returns of Yukon River fall chum salmon and ultimately for the development of escapement goals for this stock. ADF&G Research Staff (Bonnie Borba) prepared a memo for the purpose of presenting the run projections for the 2006 season to the Yukon River staff (*Projection Memo Feb-06.pdf*) and summarizes the Yukon River fall chum salmon database. The excel file *ProjectionsJTC07toBue.xls* , is the electronic version of the tables in the memo. While the data in the excel file are the best estimates at this time, the data are considered preliminary until a final project report is available for each project. Both of these documents provide an overview of the available data.

Harvests

Yukon River fall chum salmon are harvested primarily in subsistence (Busher and Hamazaki 2005; *Busher&Hamazaki_2005_RIR3A04-33.pdf*) and commercial fisheries (ADF&G 2001). The harvest data in the file *ProjectionsJTC07toBue.xls* appear to be the most accurate. It should be noted that the number of subsistence-caught fish in this file was estimated for the years 1974-1978 with the methodology footnoted. Subsistence surveys prior to 1979 were conducted too early in the fall to obtain an estimate of the catch of fall chum salmon. The file *Yukon River Catch Data .xls* is included with tab “A.19 (05)” providing the catches by fishing district. It should be noted that the two files differ for the years 1974-1978 due to the interpolation for subsistence catch and for the years 2004 and 2005 because of preliminary catch numbers. The total numbers between the two files for 1988-1990 also differed by less than 0.8% per year. While the 1988-1990 differences were present, it was felt that the differences would not dramatically influence our interpretation of the data and that the inclusion of both files would allow for a run reconstruction by fishing district if desired.

Escapement

Escapement data are generally broken up into 3 components; 1) the Tanana River, 2) the Upper Yukon in Alaska, and 3) the Yukon River upstream of the US/Canada border. Escapement data for each of these components are found by year in tab "Table 2" of *ProjectionsJTC07toBue.xls.*

<u>*Tanana River*</u>. Ground and aerial surveys have been conducted on four different portions of the Tanana River drainage, the Toklat River, Delta River, Bluff Cabin Slough, and Clearwater Lake outlet since the mid-1970's and early 1980's. Area-under-the-curve methodology using an 18.2 day residence time was used to make the escapement estimates for the Delta River (*DELTAMTD2005.XLS*)and Bluff Cabin Slough while historical run timing was used for the Toklat River (*ToklatExpansion.xls*).

Mark-recapture projects have been used to estimate the number of fall chum salmon entering the Tanana River upstream of the Kantishna River (since 1995) and Kantishna River (since 1999; *Cleary_&_Hamazaki_fds05-76.pdf*). The Toklat River is a tributary of the Kantishna while the Delta River, Bluff Cabin Slough and Clearwater Lake contribute to the Upper Tanana River.

<u>*Upper Yukon in Alaska*</u>. A mark-recapture project designed to estimate the total number of fall chum salmon moving in the Yukon River upstream of the Tanana River has been done nearly annually since 1996 (*Gordon_etal_1998_AFTR45.pdf, Underwood_etal_2000_AFTR56.pdf, Underwood_etal_2000_AFTR57.pdf, Underwood&Bromaghin_2003_AFTR62.pdf, Apodaca&Daum_2004_AFTR85.pdf)*.

Escapement is estimated for Chandalar River (sonar; *Osborn&Melegari_2002_AFTR61.pdf*), the Sheenjek River (sonar; *Dunbar&Pfisterer_2004_RIR3A04-10.pdf*), and the Fishing Branch (weir). The Sheenjek and Fishing Branch are tributaries of the Porcupine with the fishing Branch weir being operated in Canada by the Department of Fisheries and Oceans.

<u>*Upper Yukon in Canada*</u>**.** The Department of Fisheries and Oceans (DFO) have been estimating the passage of Yukon River fall chum salmon into Canada using a mark-recapture project since 1980. Escapements into tributaries entering the Yukon above the US/Canada border have been estimated by subtracting the known catch from the mark-recapture estimates.

3 Criteria for Categorizing Spawner/Recruit Data Quality – E. Knudsen

Analysis of AYK salmon run-size trends, and the possible causes for observed changes in abundance, have been hampered by both a lack of data and by concerns about the quality of some of the data that is available. Also, assessment techniques have often changed one or more times during a series of annual observations. Reliability of model outputs depends heavily on the quality of the data used in the modeling exercise. The Committee discussed the potential utility of applying an index of data quality as one metric in future modeling. Although the mechanics of such an application remain to be seen, a first step was taken to define data quality categories.

Essential data for understanding the relationship between observed escapements and subsequent recruits to the fishery and escapement is composed of brood year spawning escapement estimates as compared to total run size, comprising escapements plus stock-specific harvests, all of which must be apportioned by age at return. Examples of similar quality criteria can be found in Knudsen (2000) and http://stateofthesalmon.org/SurveyDraft.pdf.

Brood Year Escapement Data Quality
Methods for estimating spawner escapements vary over time and techniques. They can range from direct counts, to indices, to extrapolations. They can be purely enumerated, may need some minor adjustments, or may require simple to complex derivation algorithms.

Criteria for rating **escapement data quality** are:
Excellent - Consists of direct, accurate counts or observations at a location that includes practically all spawners. Methods need only minor adjustments or corrections for missing counts or observations, but no further final derivations are required.
Good – Method is based on reliable sampling or indexing technique that has been corroborated by other techniques. If expansions or derivations are made, variance of the estimate can be calculated and is reasonably small.
Fair – Method is based on sampling or indexing techniques that are generally acceptable for salmon. There are various problems with questionable observations and missing data. Data expansions or derivations are reasonably simple and the variance can be calculated.
Poor – The methods are based on questionable observations or indices. Methods may often be influenced by poor visibility or substantial missing data. If expansions or derivations are made, variance of the estimate cannot be calculated, or if it can, the variance estimate is unreasonably large. Final derivations are sometimes extrapolated based on counts or estimates from other than the target spawning stock.

Total Run Size Data Quality
Total run data quality is affected by escapement data quality, as described above, as well as harvest data quality, and the age apportionment quality. So the effects of total run size data quality are compounded over the three component estimates, and a composite rating should be created by assigning the lowest rating of the three component data types.

Criteria for rating **harvest data quality** are:
Excellent – Harvest numbers consist of direct, accurate counts or observations from a specific location where all harvests can be attributed to the stock in question. Total catch may be estimated by expanding a weighed subsample to the total weight of the entire catch if all fish are attributable to the stock in question.
Good – Harvest estimates consist of direct, accurate counts or observations from a specific location where the contribution of the stock in question can be assigned based on some reliable characteristic such as scale pattern recognition. The method for assigning harvested fish to stocks is verified each year.
Fair – Catch composition of the harvest is based on techniques which themselves have some questionable methods or are estimated by subtraction from other estimated stock harvests.
Poor – Catch composition of the harvest is guessed based on some logic about the relative run sizes or timing patterns of the mixed stocks or estimated from a relationship developed in only a few recent years, but not based on information from the current year.

Criteria for rating **age composition data quality** are:
Excellent – Age composition estimates based on a reliable, repeatable technique and adequate samples taken directly from the population in question such that the variance of the age estimate is very small. Age composition estimates represent the year to which the composition is applied.
Good – Age composition estimates based on a reliable, repeatable technique and adequate samples are usually taken from the population in question and the variance of the age estimate is reasonable. Age composition estimates may be from another year if there is low interannual variability.
Fair – Estimates are based on somewhat questionable techniques and somewhat small sample sizes. Age composition estimates are from another year even though there is noticeable interannual variability. Age composition estimates are from another portion of the run within the same year (e.g., estimates from the commercial fishery are applied to the spawning grounds).
Poor – Age composition estimates are extrapolated from other years or other stocks. Age composition estimates are from only one or two other years. Age composition estimates are from another portion of the run in other years (e.g., estimates from the commercial fishery are applied to the spawning grounds).

4 Updated Analysis of Productivity Changes in the Kwiniuk, Anvik, and Andreafsky Chum Salmon Stocks – D. Goodman

Introduction

The AYK chum salmon stocks underwent a decline which has become cause for management concern. My previous report to AYK SSI ("Uncertainty analysis of stock recruitment relationships for selected western Alaska chum stocks," D. Goodman, November 14, 2004) showed that the underlying deterministic stock recruitment relationship was ambiguous (neither the Ricker nor the Beverton-Holt nor any intermediate was a convincing fit), but the temporal changes in recruits per spawner showed a striking pattern: the residuals from a Ricker fit showed a brood-by-brood pattern with a distinct declining trend; and the detrended residuals showed a high positive correlation among the three stocks examined (Kwiniuk, Anvik, and Andreafsky). This confirmed that there was a shared downward trend in productivity, and added the new conclusion that the decline is at least modulated, and possibly driven, by some regional factor causing annual variation which is affecting several stocks simultaneously across a broad spatial expanse.

Since the time of that report, the data series of brood tables has been extended by a few years, and revised. The new data series show that the low productivity has continued for all three stocks, up through the last complete broods reported.

The purpose of the present analysis is to verify whether the pattern I reported in 2004 has persisted, and to attempt a more robust analysis which does not use the Ricker model (since the Ricker was a poor fit in any case).

The present analysis is based on information received from ADFG by way of Eric Knudsen in May 2006. The files were transmitted as Excel spreadsheets, one for each of the three stocks. The Kwiniuk file had complete brood information for broods 1965-1998, and complete run, escapement and harvest information for years 1965-2004. The Anvik file had complete brood information for broods 1972-1998, and nearly complete brood information (only age 7 returns missing, which in any case make up a miniscule fraction of the returns) for 1999; complete run and harvest information for 1979-2002 (nearly complete for 1978); and escapements for 1972-2005. The Andreafsky file had complete brood information for broods 1972-1998, and nearly complete brood information (only age 7 returns missing, which in any case make up a miniscule fraction of the returns) for 1999; complete run and harvest information for 1979-2002 (nearly complete for 1978); and escapements for 1972-2004.

The files of information received constitute "data" in the loose conventional sense, that they are tables of numbers which may be examined in a search for patterns and relationships. It must be understood, however, that these tables do not constitute "data" in the strict statistical sense of directly reporting actual observations (counts and measurements). The tables of brood, run, harvest, and escapement information are actually *estimates* obtained by extrapolation, interpolation, and expansion of underlying *data* (counts and measurements in samples), and the underlying data were not provided for this analysis. The distinction is relevant, because the extrapolations, interpolations and expansions introduce their own errors and uncertainties, of magnitudes which, under these circumstances, are completely unknown.

The analyses reported in the following sections accept the brood, run, harvest and escapement tables at face value, as if they were free of "measurement error," when in fact they must contain such error, both from the underlying observations and from the estimation procedure, which might, therefore, distort or obscure the apparent relationships, and might possibly even give rise to the spurious appearance of relationships and patterns. This must be borne in mind in interpreting the relationships and patterns which were found. This should also be considered carefully in designing the future collection and documentation of stock-recruit information, so that, in the future, analyses will be able to estimate the magnitude of the error variation itself, which will allow for a more rigorous separation of signal from noise and artifact.

Time Series of Runs, Harvests and Escapements

The decline of the chum stocks involved three detectable components: a sharp transition (*not* simultaneous in all three stocks), a more gradual trend, and annual variation around the trend.

This is readily seen in the simple harvest and run size history of the Kwiniuk stock (Figure 1). The historic peak run size and harvest occurred in 1983, still leaving a large spawning escapement; but in 1985 the run was lower than had ever been recorded before in the data set starting with 1965. Harvests were greatly reduced in 1984, and stayed low, but the run sizes never really recovered. Since 1985 there were a few runs that reached into the lower-mid-range of the pre-1985 runs, but none that replicated the higher ranges of the pre-1985 runs. Harvests prior to 1989 were at times a considerable fraction of the run, perhaps playing a role in the downward trend; but from 1989 on, the harvests were small.

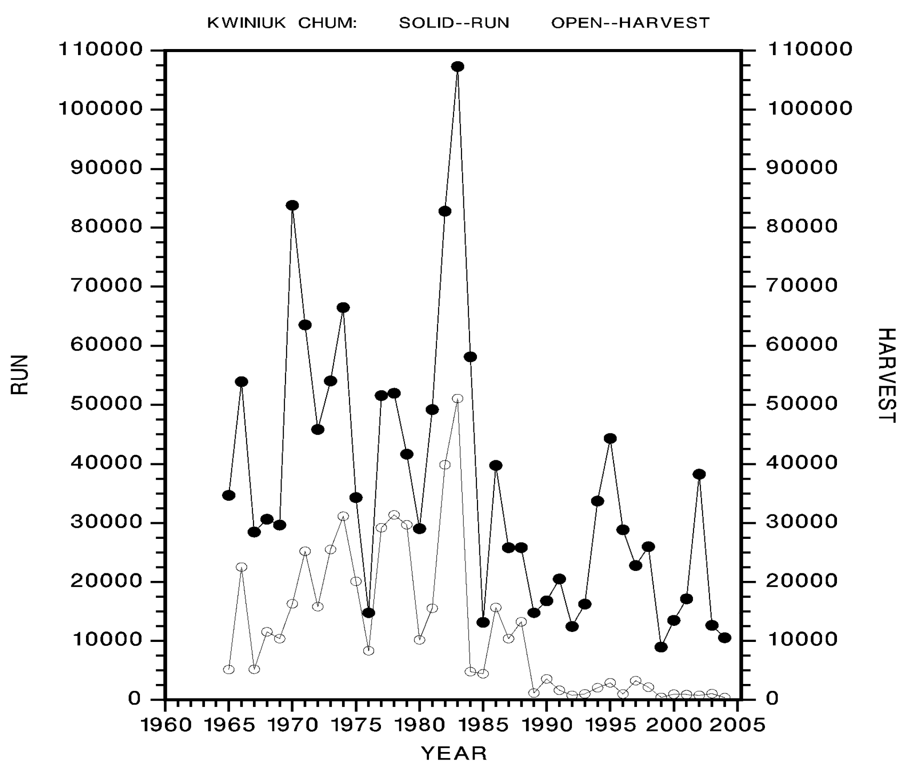
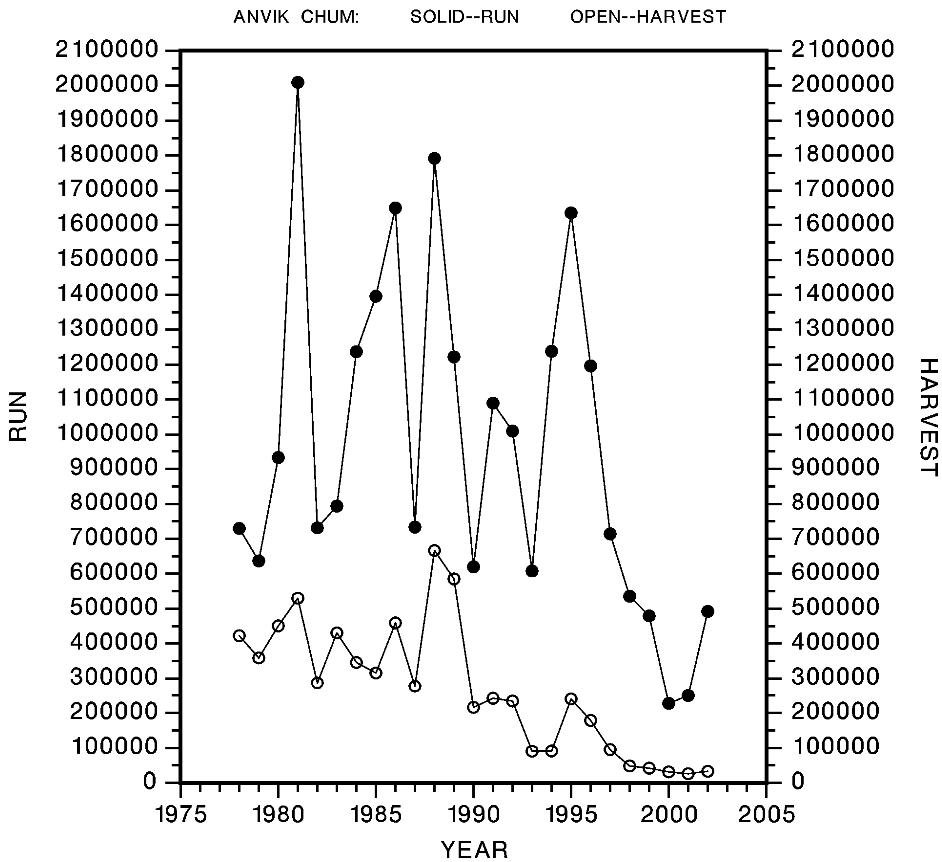


Figure 1

The runs for Anvik show broad variation from 1978-1997, and then shifted to a lower range starting in 1998 (Figure 2). The last really high run size was in 1995. The runs from 1998 and after were all lower than had been recorded before. Prior to 1989 the harvests at times took a considerable fraction of the run, but from 1989 on the harvests were consistently small. For the Anvik runs, 1985 (or thereabouts) did not constitute a breakpoint.

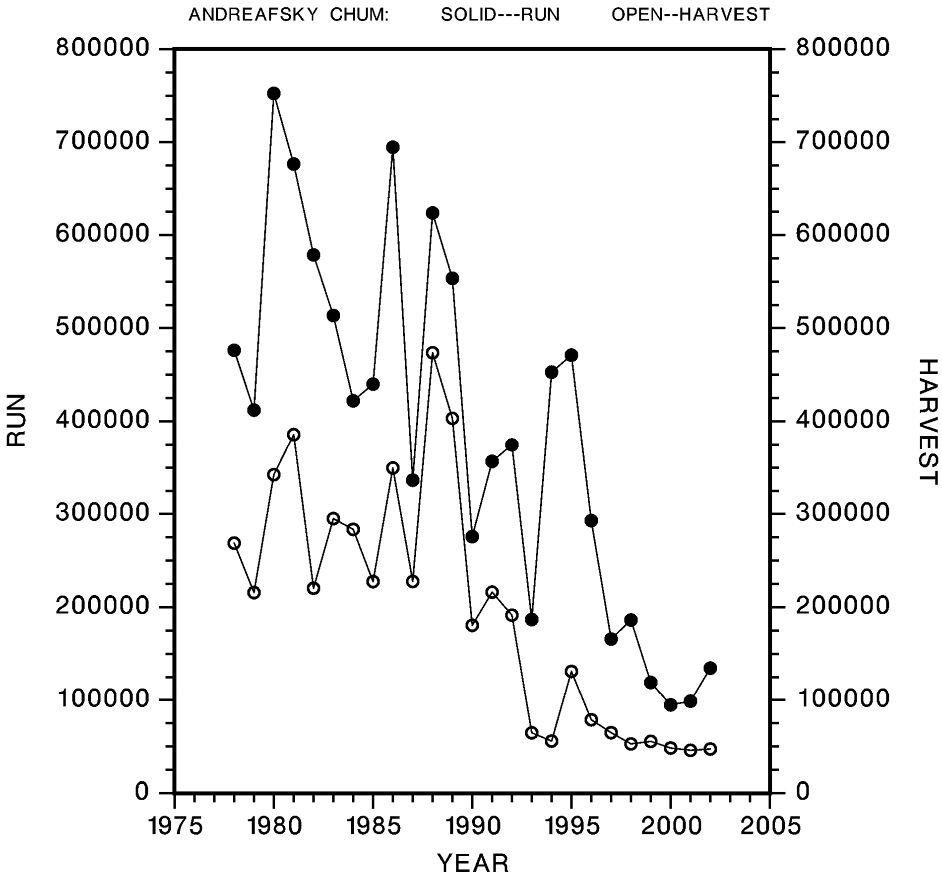
Figure 2.



The runs for Andreafsky show broad variation over a very definite downward ratcheting trend from 1978-1997, and then shifted to a lower range of consistently depressed runs starting in 1998 (Figure 3). The last significant upward swing in run size was in 1994-1995. The runs from 1997 and after were all lower than had been recorded before.

The harvests were substantial but fairly consistent prior to 1987; were episodically quite a high fraction of the run from 1987 to 1992; and then stabilized at again taking around half the run. The Andreafsky runs show a breakpoint around 1997, similar to the Anvik, but do not show a clear breakpoint around 1985 when the Kwiniuk shifted.

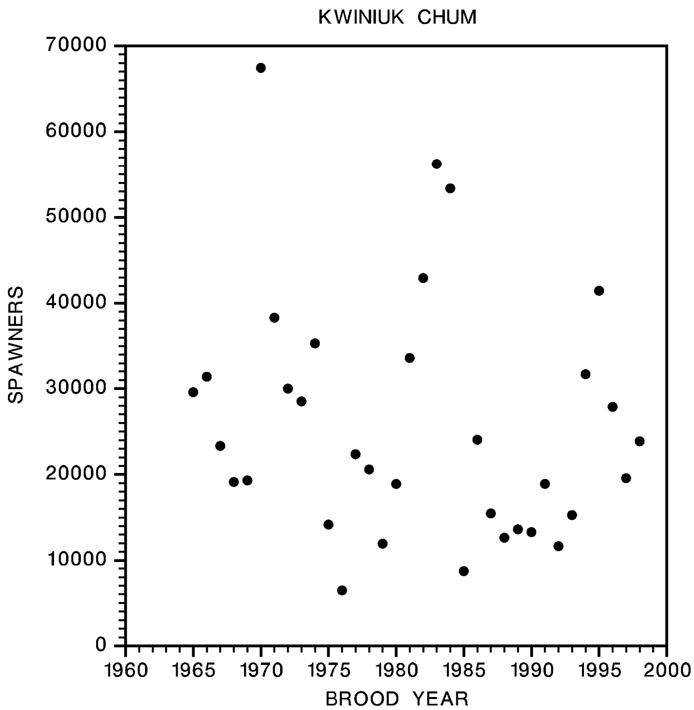
Figure 3.



The big changes in run size for these three stocks leave open one possibility that some sort of "perfect storm" of chance events decimated one run, and a few that followed, with consequences for community and ecosystem in changes in the freshwater, estuary and plume side of the system (perhaps mediated by marine derived nutrients or spawner conditioning of gravel) which have proven self-perpetuating. This hypothesis does not lend itself to much statistical examination, because the change constituted a sample of one per stock, and it is odd that the time of the shift in the Kwiniuk run did not coincide with those in the Anvik and Andreafsky. The hypothesis is also somewhat unappealing in that it involves two unidentified mechanisms which would need to be elucidated: what caused the initial run size reduction, and what caused the continued reduced productivity after the initial string of small runs?

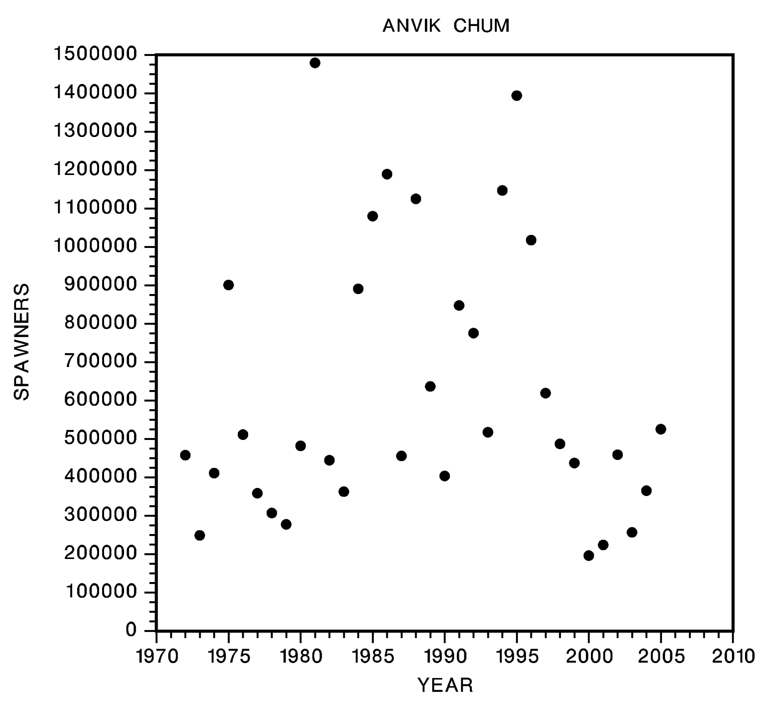
Kwiniuk spawning escapements, which are a direct function of management, in contrast to the run sizes, showed a much more modest long term declining trend (Figure 4), staying almost in the same broad range throughout this history. There is a peculiar tendency toward pairs of consecutive escapements to be very close (e.g., 1965-1966, 1968-1969, 1972-1973, 1977-1978, 1983-1984, 1988-1989, and 1989-1990); no plausible hypothesis has come to mind for this phenomenon. This should be pursued with the people who actually did the data collection in the field, to make sure that this phenomenon is not an artifact of the data collection or data handling.

Figure 4



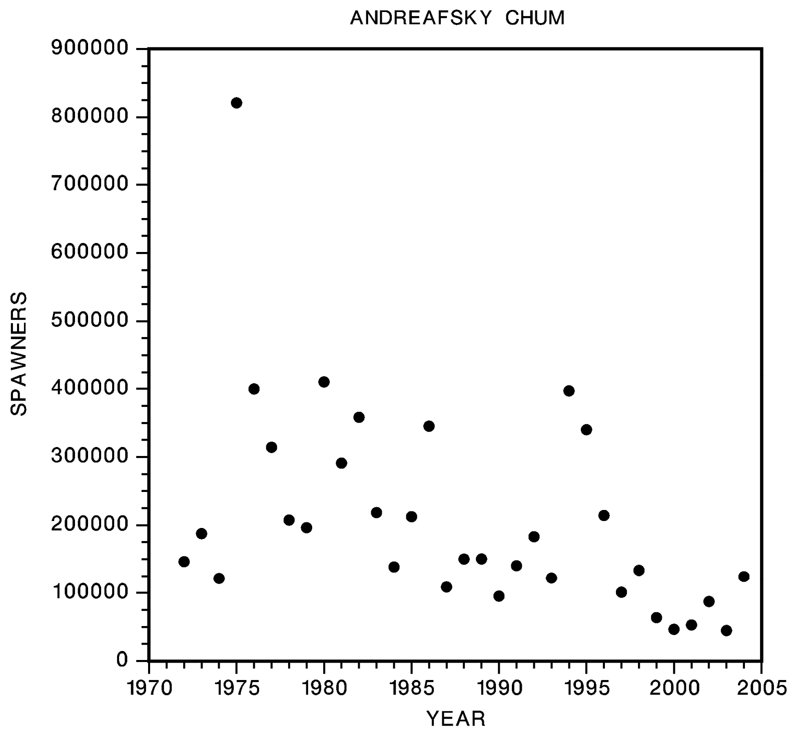
Anvik spawning escapements, on the other hand, showed no long term declining trend (if anything they trended upward from 1972 to 1996), except for the definite and abrupt shift to a lower range of values in 1998 (Figure 5). There is some suggestion of frequent similarity of values in consecutive pairs, but this is much less striking than in the Kwiniuk.

Figure 5.



Andreafsky spawning escapements showed a definite declining trend, an extreme high outlier in 1975, confinement to a low range of values starting in 1997, and only hints of frequent similarity of values in consecutive pairs 1998 (Figure 6).

Figure 6.



Time Series of Recruits Per Spawner

Several analyses have shown that underlying the decline in the chum stocks was a decline in the per capita productivity (Mundy committee). In the Kwiniuk there was an abrupt shift to a lower range of recruits per spawner starting with the 1981 brood, after a historic high from the 1979 brood (Figure 7). (Note again the puzzling frequency of consecutive pairs with very similar values.) The 1981 through 1984 broods, which all produced very low recruits per spawner, were all spawned in years while the runs were still high (Figure 1 again), so if the "perpetuating feedback" hypothesis is true, the mechanism must have required the cumulative effects of several years before it began to operate.

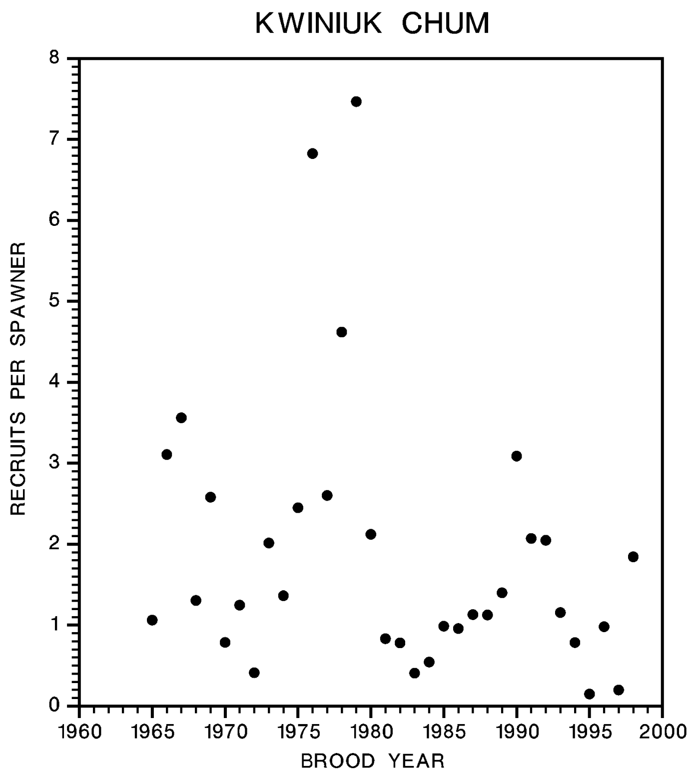
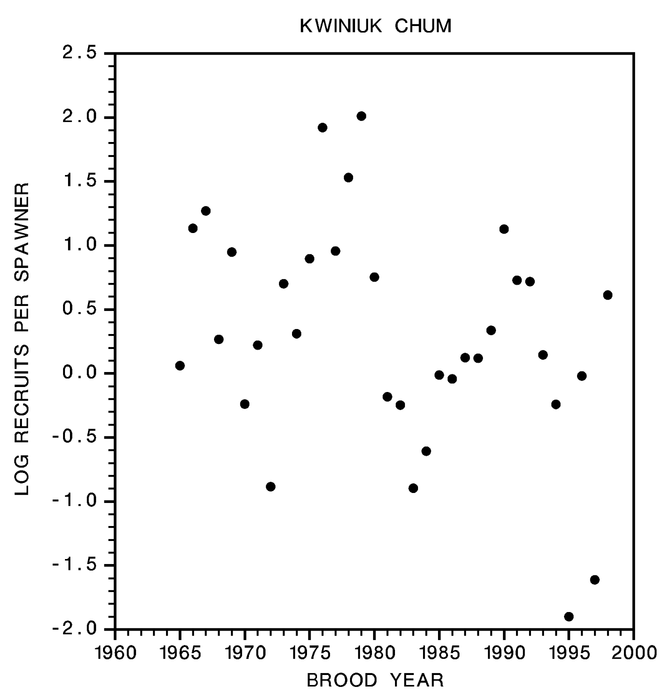


Figure 7.

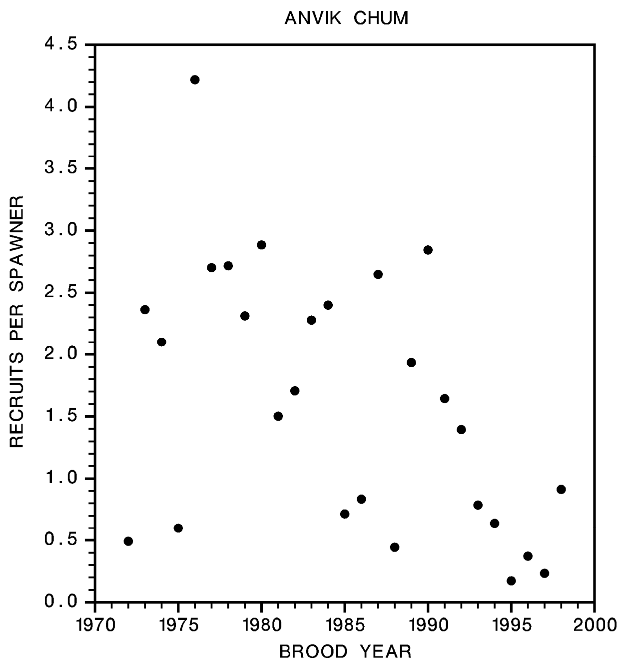
In the log space, the declining productivity for the Kwiniuk stock looks more or less linear (Figure 8).

Figure 8.



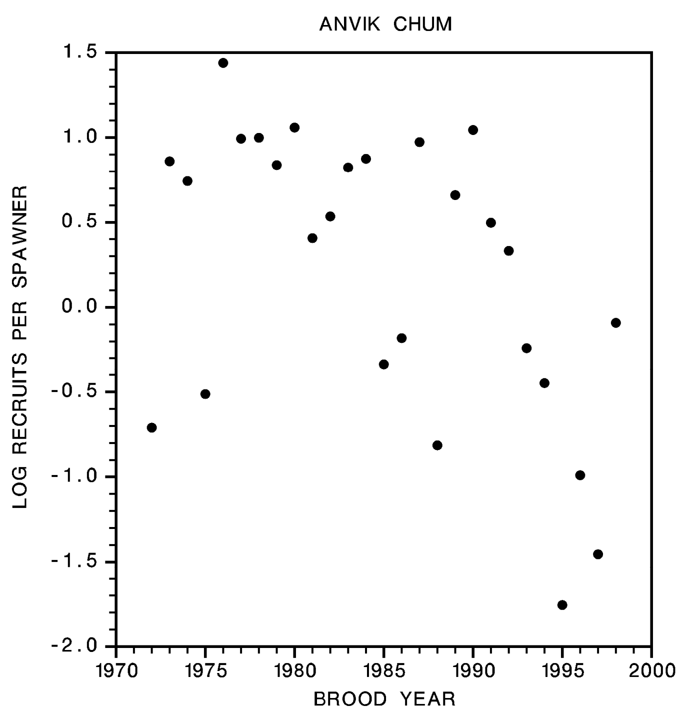
In the Anvik, the shift to a lower range of recruits per spawner took place over the 1991-1993 broods (Figure 9). Recall that the Anvik runs did not become consistently depressed till 1997.

Figure 9.



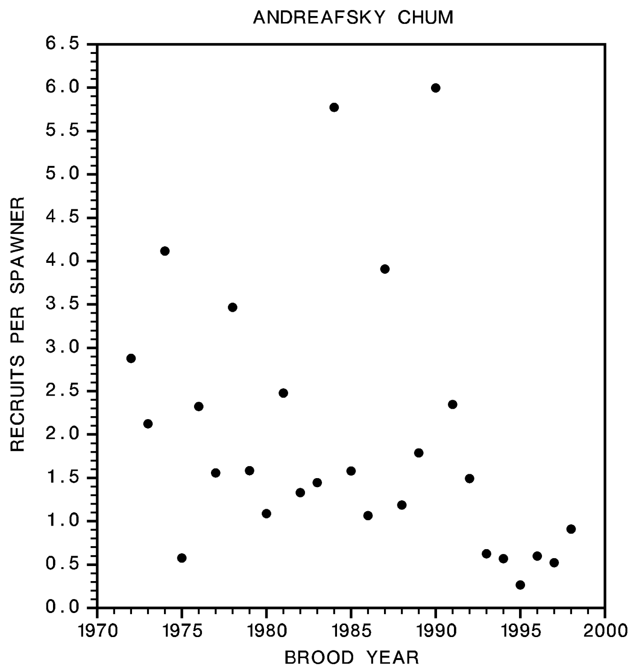
In the log space, the decline in productivity for the Anvik stock looks more or less linear (Figure 10).

Figure 10.



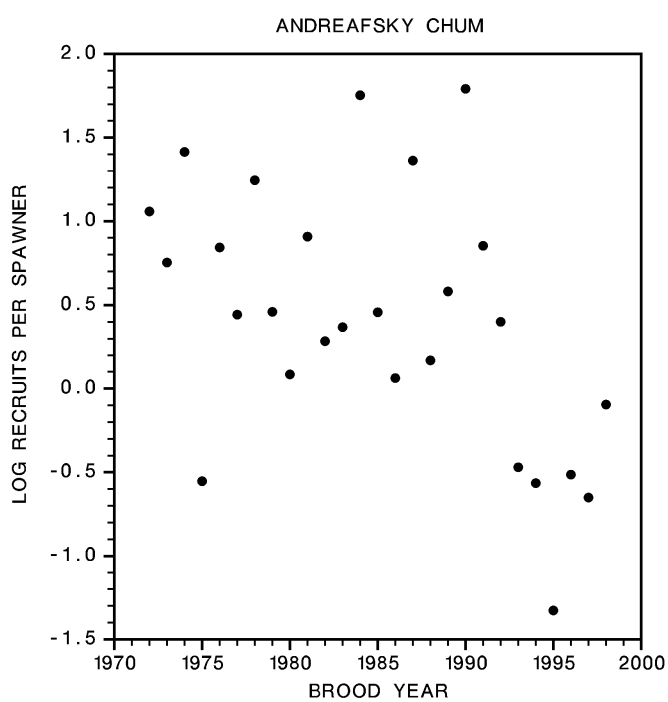
In the Andreafsky, the shift to a lower range of recruits per spawner took place with 1993 brood (Figure 11), and was abrupt. The Andreafsky runs became consistently depressed starting in 1997.

Figure 11.



In the log space, the decline in productivity for the Andreafsky stock looks more or less linear (Figure 12).

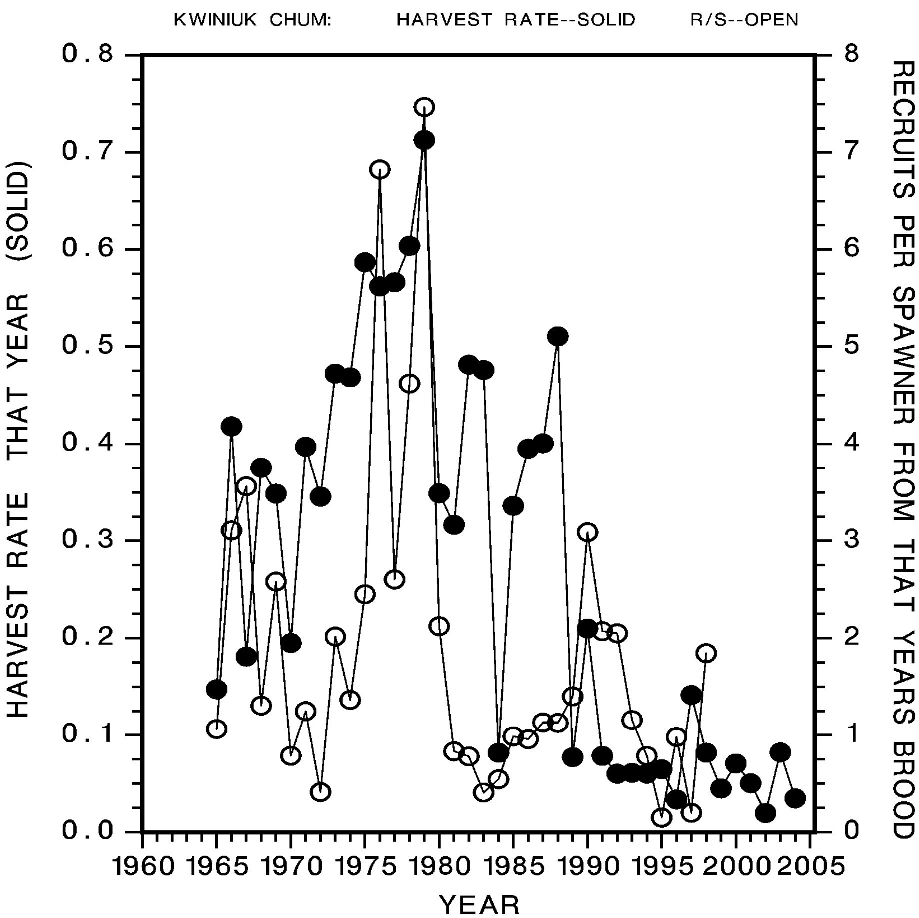
Figure 12.



Harvest Rates

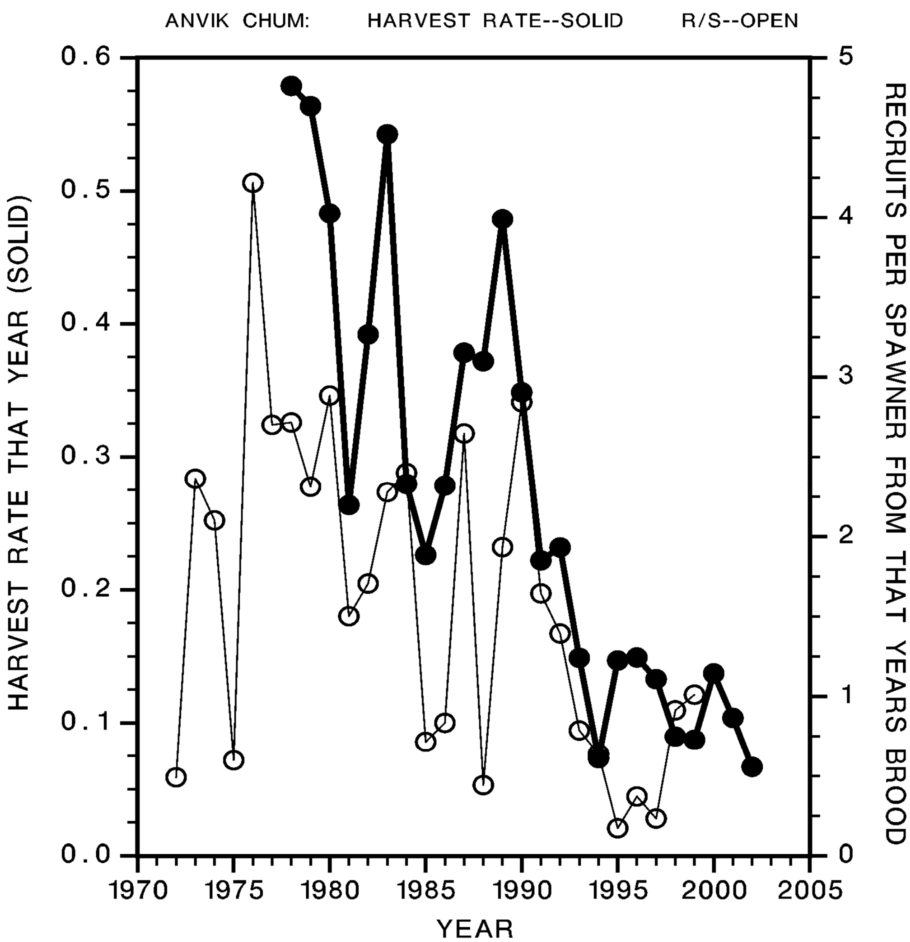
The harvest rate on the Kwiniuk stock shifted down sharply in 1989, which was 8 years *after* the birth of the brood where recruits per spawner shifted to the low range (Figure 13). Before the 1981 drop in productivity, the productivity of the Kwiniuk stock had been not much better than modest (usually around 2 recruits per spawner), and the harvest rate also had been modest (around 40%). After the decline in productivity, the recruits per spawner were mostly below replacement, and the harvest rate was mostly below 10%.

Figure 13.



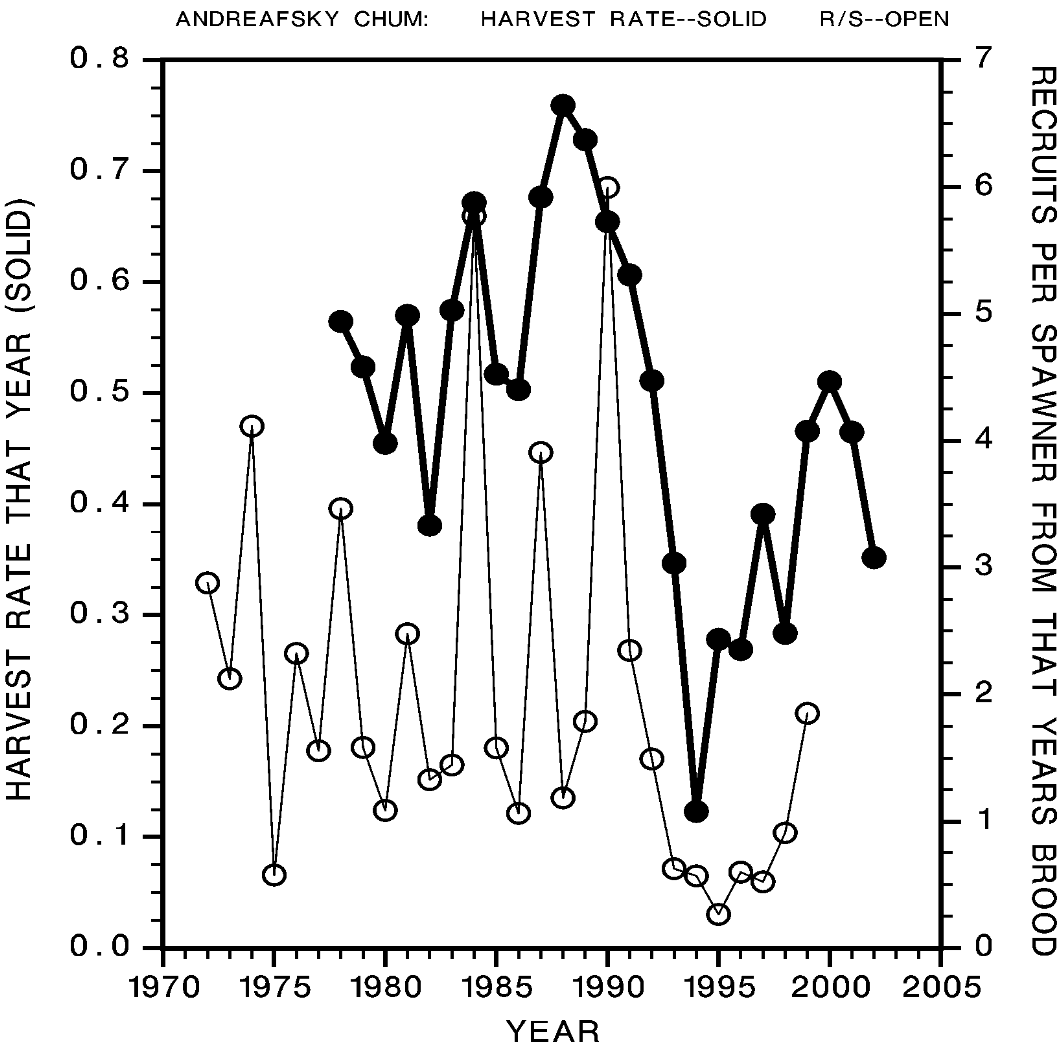
For the Anvik stock, the shift in productivity and in harvest rate took place about simultaneously (Figure 14). The harvest rates and productivities were similar in magnitude to those for the Kwiniuk, but the timing and pattern of the main shift was different.

Figure 14.



For the Andreafsky stock, the shift in harvest rate and productivity took place about simultaneously (Figure 15). The Andreafsky was not more productive than the Kwiniuk or Anvik, but it was harvested harder, even after the drop in productivity.

Figure 15.



Spawner-Recruit Relationships

The data still do not show a very clear stock recruit relationship (Figure 16 for Kwiniuk; Figure 17 for Anvik; Figure 18 for Andreafsky).

Figure 16.

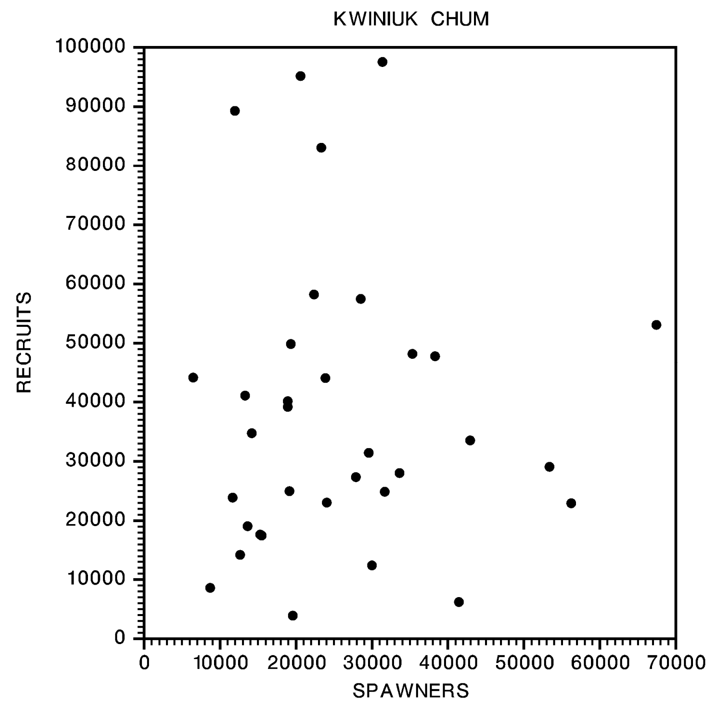


Figure 17

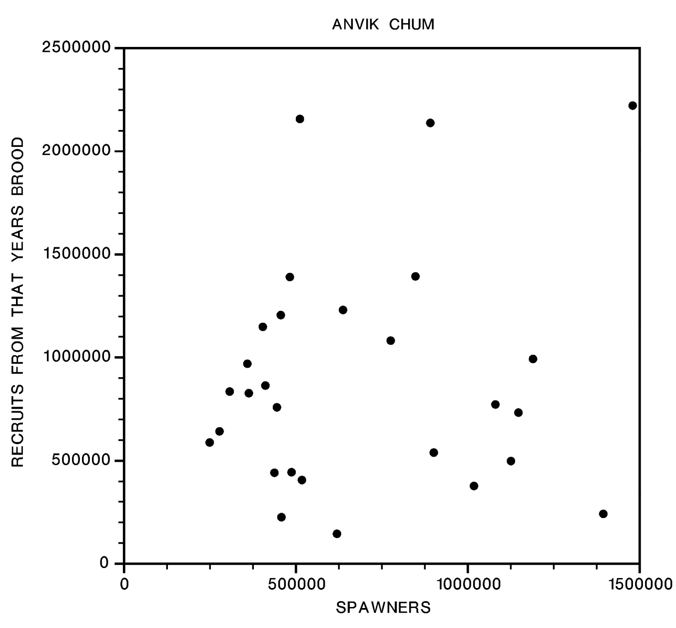
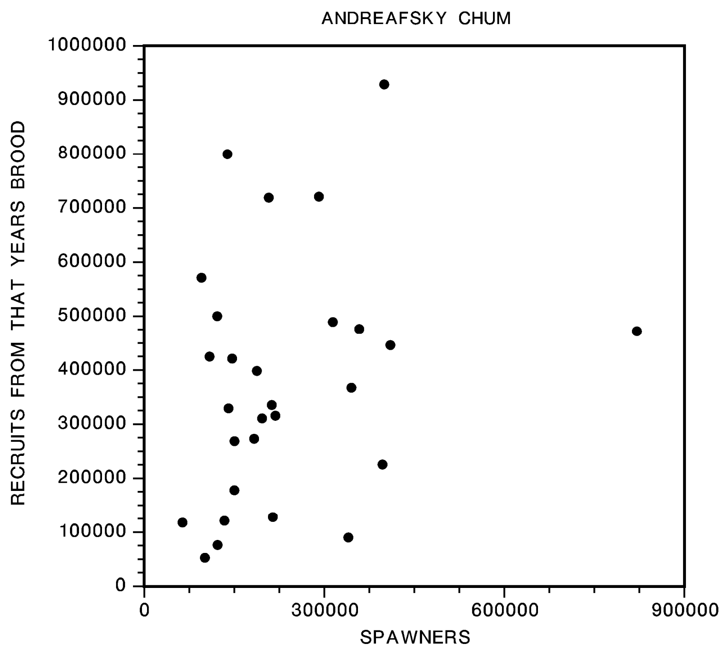


Figure 18.



The usual transformations for obtaining a linear relation from a Ricker or Beverton-Holt model failed to distinguish convincingly between the two, and left an uninspiring scatter in the data (Figures 19 and 20 for Kwiniuk).

Figure 19.

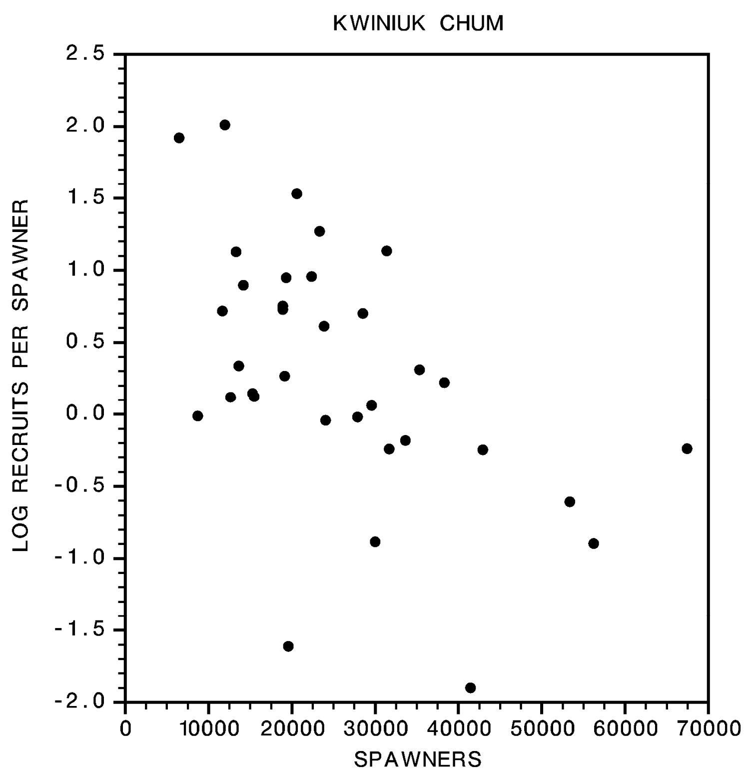
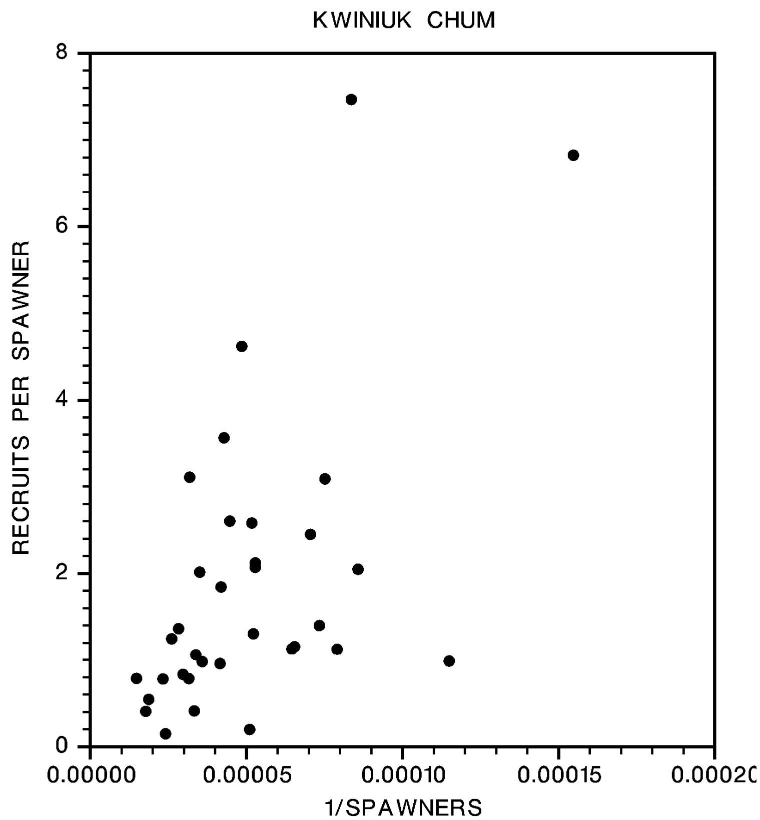


Figure 20.



Other transformations were equally unimpressive (Figures 21 and 22 for Kwiniuk).

Figure 21.

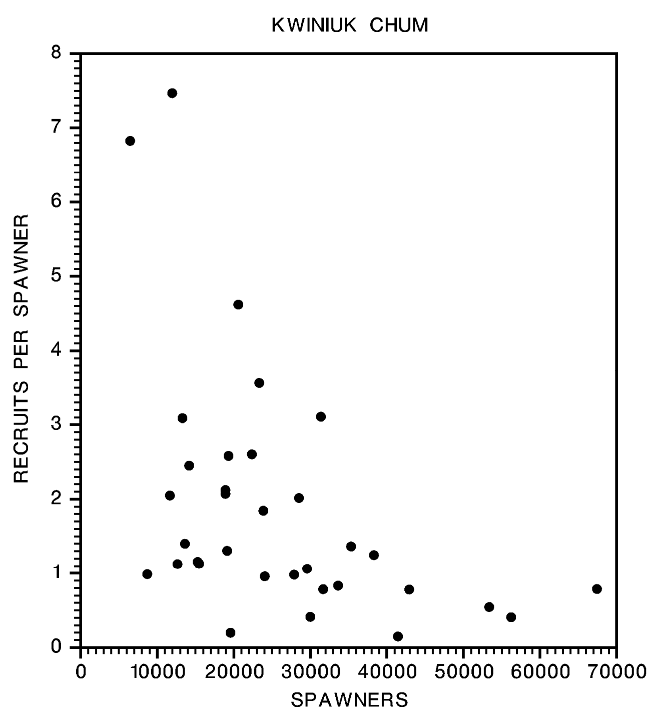
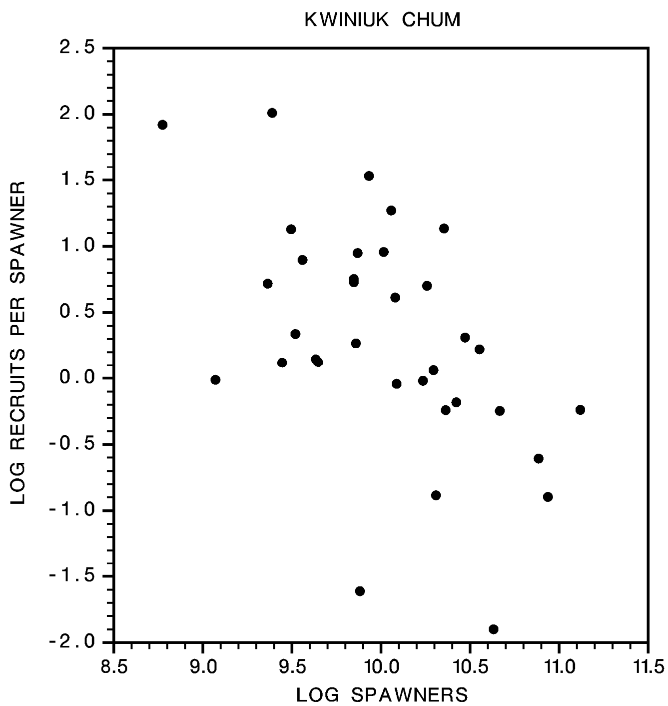


Figure 22.

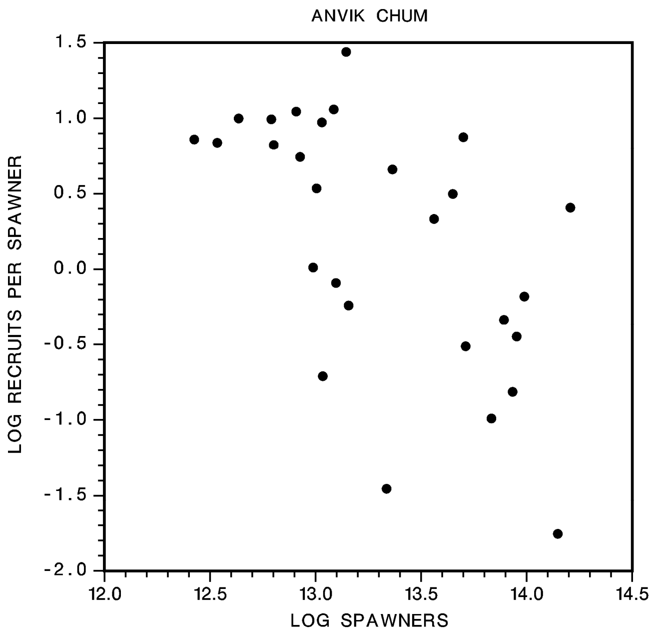


The log-log plot (Figure 22) showed a quite linear pattern and more or less homogenous normal scatter, but this can arise under the "null" model of recruits and spawners being *independently* log-normally distributed (which of course is reasonably consistent with the appearance of the untransformed plot, Figure 16). Under that null model, in the log-log space, the theoretical (asymptotic) correlation between the x and y axes will be $r_{xy} = -\sigma_x / (\sigma^2_x + \sigma^2_y)^{1/2}$ and the regression slope will be $\alpha = r_{xy} / \sigma_x$ where σ is the standard deviation along that axis. For the special case of $\sigma_x = \sigma_y$ this gives a slope of -0.7072 and a regression r-squared of ½. With the actual variances in Figure 22, the r-squared expected under the null model is 0.274 and the slope is -0.990. In fact, the regression gave an r-squared of 0.290 and a slope of -0.875.

For the Anvik, the regression of log recruits per spawner on log spawners gave an r-squared of 0.345 and a slope of -0.960, compared to the null model expectation of an r-squared of 0.273 and a slope of -1.04. The log-log plot shows the roughly linear relationship (Figure 23).

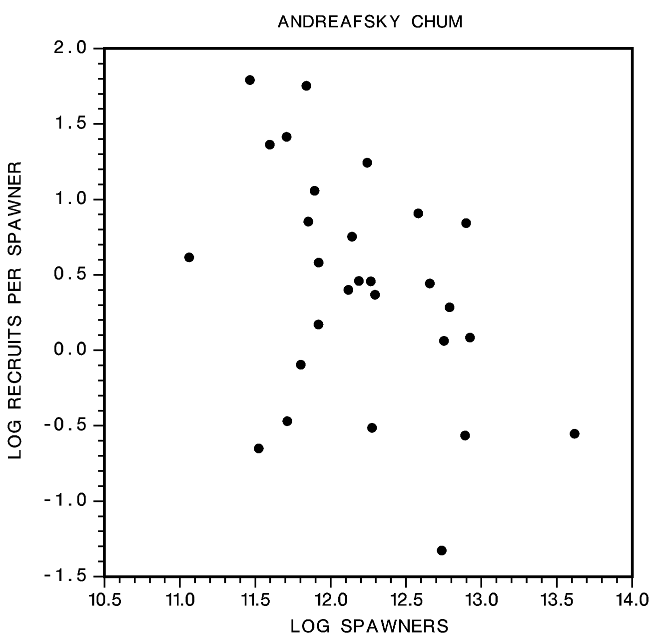
For the Andreafsky, the regression of log recruits per spawner on log spawners gave an r-squared of 0.212 and a slope of -0.680, compared to the null model expectation of an r-squared of 0.314 and a slope of -1.07). The log-log plot shows the roughly linear relationship (Figure 24).

Figure 23.



Similar log-log plots resulted for the Andreafsky stock (Figure 24).

Figure 24.

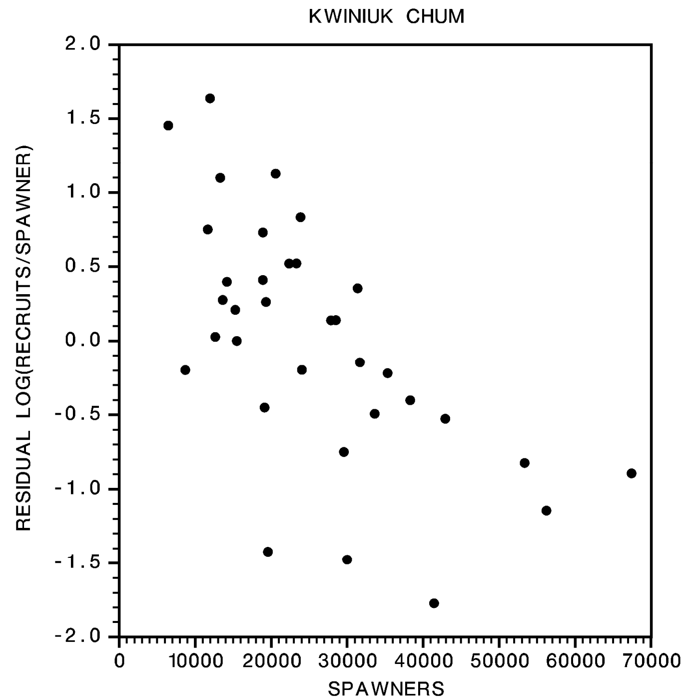


Stock-Recruit in the Detrended Time Series

The data showed a broad long term downward trend in the recruits per spawner for all three stocks, nearly linear in the log space (Figures 8, 10 and 12), but still with very large scatter.

For Kwiniuk, the residual from linear regression of log recruits per spawner on year shows that, after this temporal detrending, the density dependence remains (Figures 25 and 26), and in fact is noticeably clearer than before detrending (compare Figure 26 with Figure 22). The r-squared of the regression of log recruits per spawner on log spawners was 0.290, whereas the regression of log recruits per spawner on log spawners was 0.416.

Figure 25.



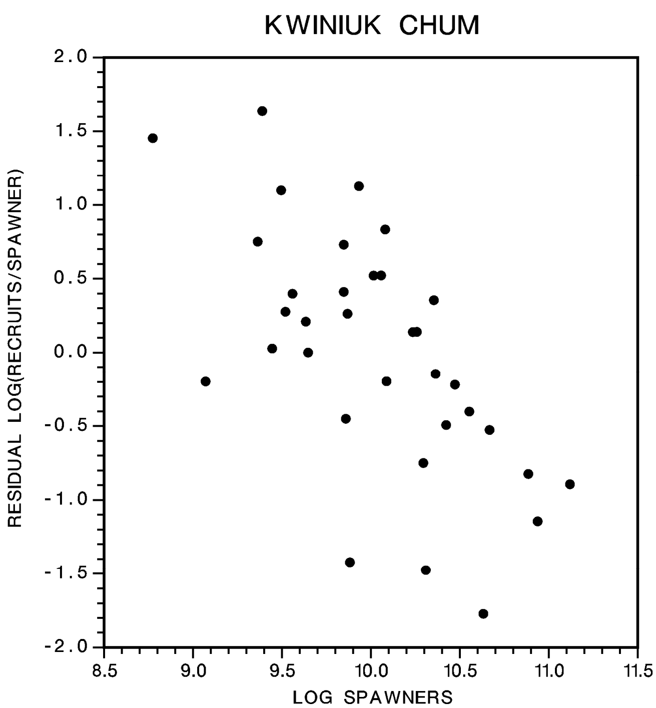
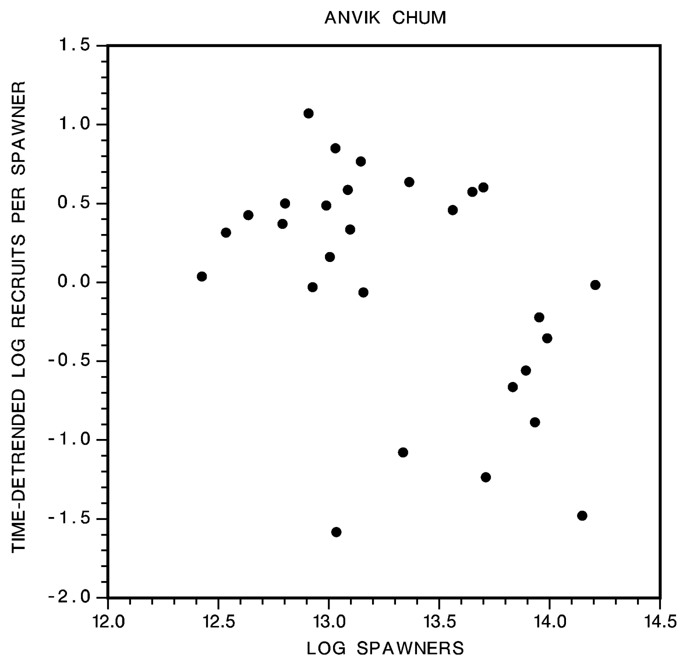
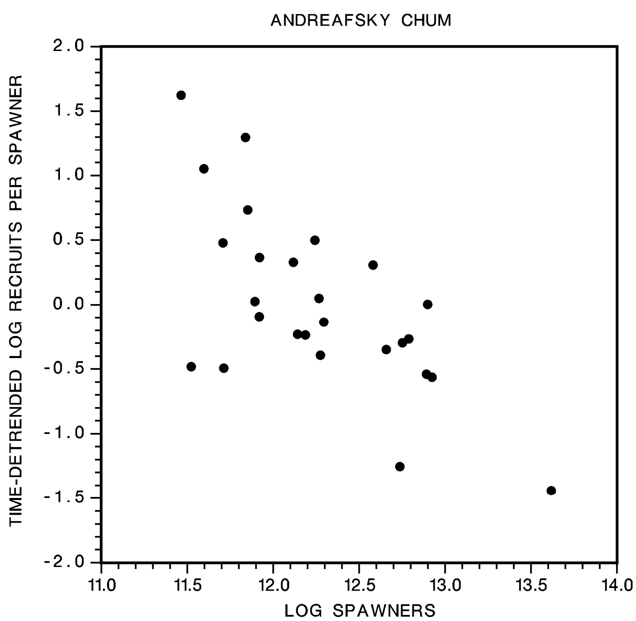


Figure 26

For Anvik the residual from linear regression of log recruits per spawner on year shows that, after this temporal detrending, the density dependence remains (Figure 27), but the regression is less clear than before detrending (compare Figure 27 with Figure 23). The r-squared of the regression of log recruits per spawner on log spawners was 0.345, whereas the regression of time-detrended log recruits per spawner on log spawners was 0.207.

Figure 27.





For the Andreafsky the residual from linear regression of log recruits per spawner on year shows that, after this temporal detrending, the density dependence remains (Figure 28), and, as for the Kwiniuk but not the Anvik, the regression is noticeably clearer than before detrending (compare Figure 28 with Figure 24). The r-squared of the regression of log recruits per spawner on log spawners was 0.212, whereas the regression of time-detrended log recruits per spawner on log spawners was 0.449.

Figure 28.

First-differencing the recruits per spawner and spawner time series does not lead to a clearer stock recruitment relationship (Figures 29-33 for Kwiniuk), so the dominant source of departures from consistent stock recruit relationships must be strong year effects rather than a more gradual drift in the relationship over time.

Figure 29.

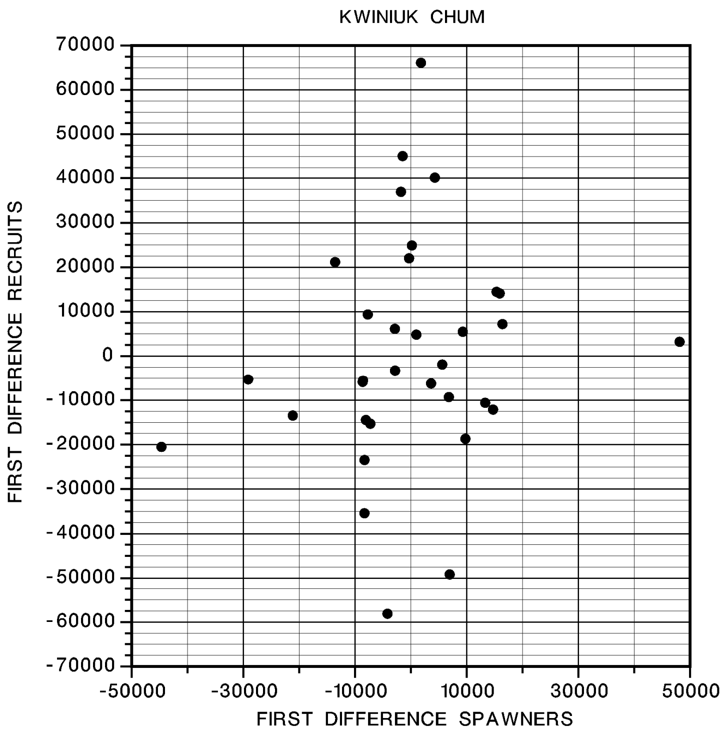


Figure 30.

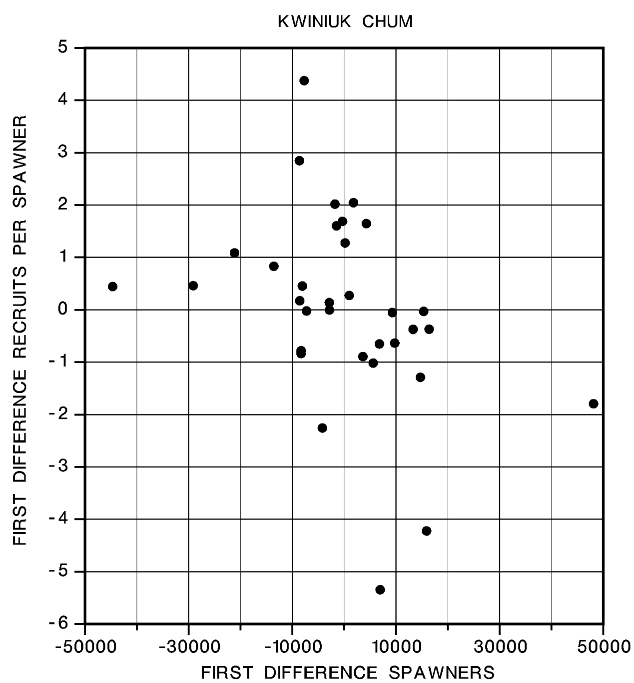


Figure 31.

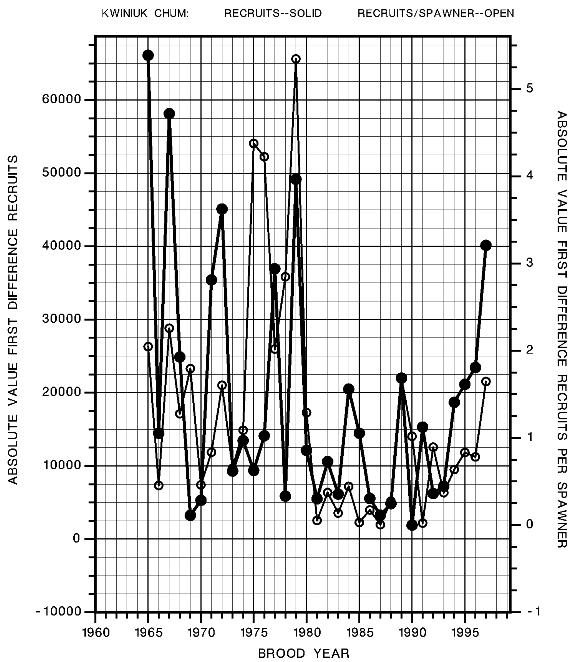


Figure 32.

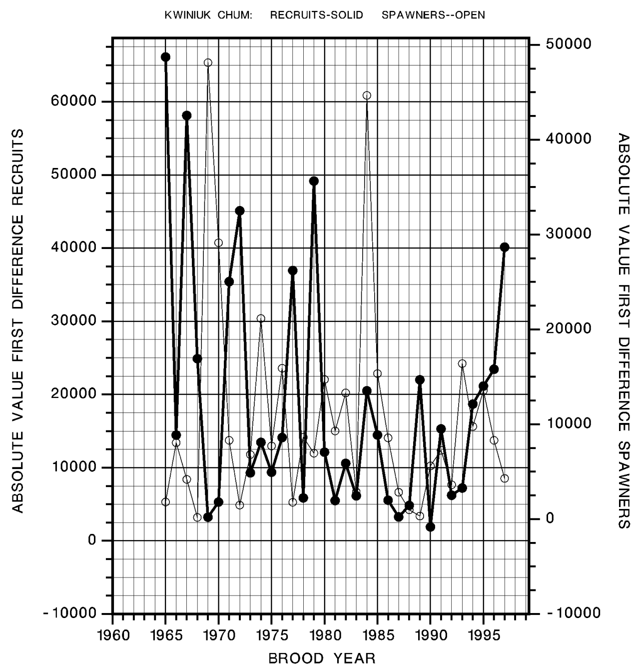
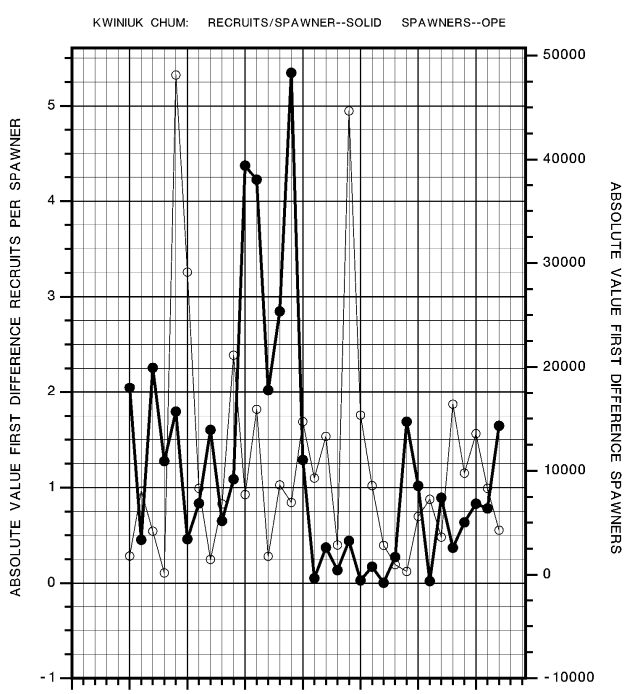


Figure 33.



Time Series of Departure from the Time Detrended Relation Between Log Recruits Per Spawner and Log Spawners

A multiple regression of log recruits per spawner jointly on log spawners and year was carried out, thus sidestepping the choice of a particular conventional stock recruit model, and staying true to the pattern of by-brood density dependence which was actually observed factoring out the time trend in the log recruits per spawner. The summary table of results from the multiple regression is

Stock	Kwiniuk	Anvik	Andreafsky
r-squared	0.501	0.426	0.606
beta coefficient for year	-0.468	-0.293	-0.686
beta coefficient for density	-0.624	-0.465	-0.646

The multiple regressions account for about half the variability in log recruits per spawner. Residuals from this regression still show a strong year effect (Figures 34, 35 and 36).

Figure 34.

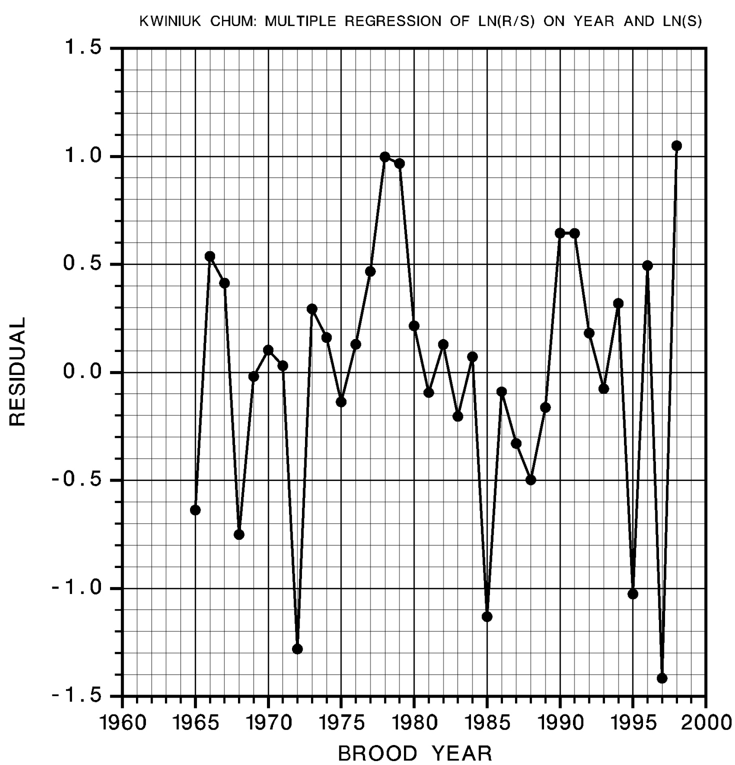


Figure 35.

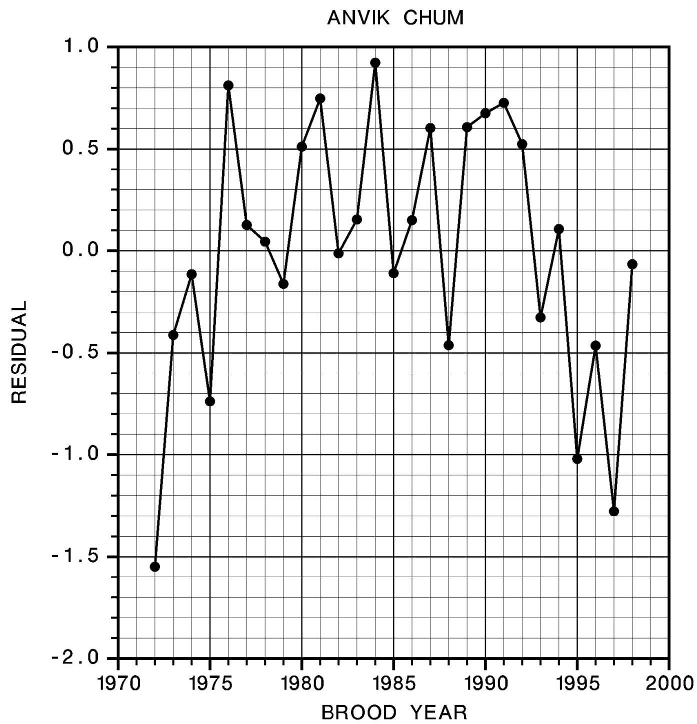
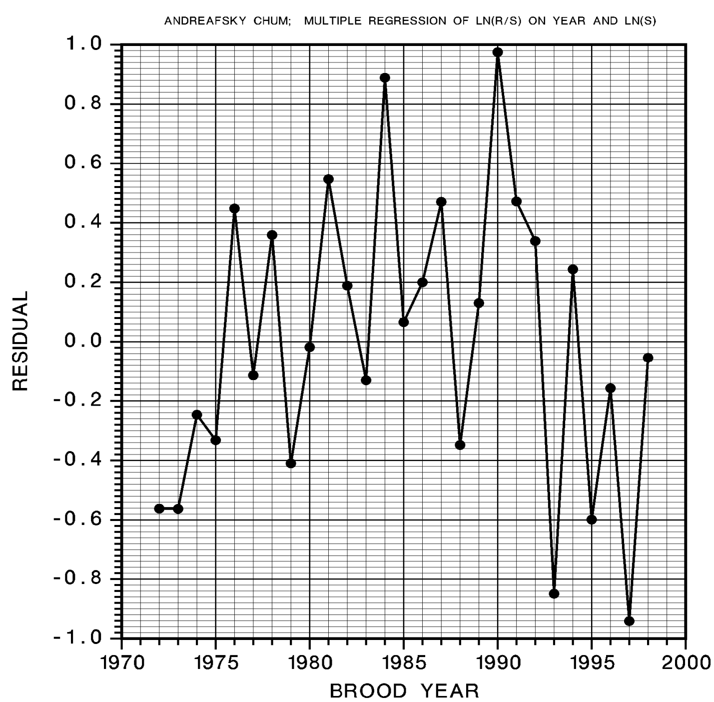


Figure 36.



The residuals from the separate regressions for the Kwiniuk, Anvik, and Andreafsy stocks show considerable temporal coherence across the stocks, as in the 2004 analysis. The three time series of these residuals are shown overlain in Figure 37.

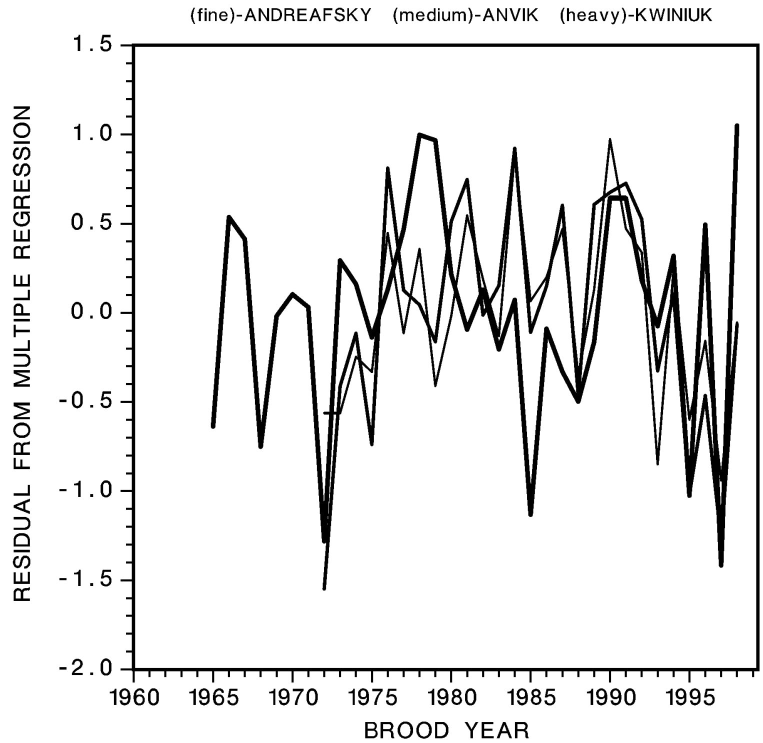


Figure 37.

The correlation matrix among the three residual time series is

	[1]	[2]	[3]
[1] Kwiniuk	1.000	0.524	0.415
[2] Anvik	0.524	1.000	0.847
[3] Andreafsky	0.415	0.847	1.000

A principal component analysis on the correlation matrix of the three residual times series showed 74% of the variance accounted for by the first component which is essentially a simple sum of the three. The corresponding eigenvector is

[1] Kwiniuk	0.481
[2] Anvik	0.632
[3] Andreafsky	0.607

These results reinforce the conclusions from the 2004 analysis. All three stocks exhibit a strong downward long term trend in density- corrected recruits per spawner; and the strong year effects after correcting for both the trend and density show strong driving by some regional factor that affects all three stocks more or less synchronously. Future research should attempt to determine the identity and nature of that driver (or drivers).

5 *The effect of Marine Derived Nutrients on salmon escapement – M. Adkison*

Research on marine-derived nutrients imported to freshwater in salmon carcasses has increased dramatically in recent years (Gende et al. 2002, Stockner 2003, Willson and Halupka 1995, Helfield and Naiman 2006). Nutrients imported in salmon carcasses have been found in virtually all ecosystem components, including juvenile salmon. These marine-derived nutrients could be important to the productivity of the components of the ecosystem on which juvenile salmon depend, and thus result in increased production of salmon (Mathisen 1971, Hartman and Burgner 1972, Mathisen and Poe 1981). Declines of some sockeye stocks have been attributed to reduced nutrient loading because of low escapement (Schmidt et al. 1998; Stockner et al. 2000).

The potential for the productivity of salmon to depend upon marine-derived nutrients from salmon carcasses is larger for species and populations that (1) spend long periods in freshwater and (2) use freshwater environments where nutrients could be retained for long periods. A typical sockeye salmon population fills both of these requirements, spending one to two years rearing in a lake. A recent study (Uchiyama 2007) found that sockeye smolt had higher concentrations of marine-derived nutrients when water residence times in the nursery were high; however, the factors that affected the level of marine-derived nutrients in smolts did not appear to affect the productivity of the stock. Coho and Chinook salmon also spend an extended period in freshwater, albeit in streams (some coho use lake habitats). Chum and pink salmon, which typically immediately migrate to the ocean, are less likely to benefit from marine-derived nutrients.

Despite the potential effects of marine-derived nutrients on some salmon populations, this mechanism probably should not be a major focus of investigating escapement goals to the AYK region. The species and populations of most concern (chum, chinook, and coho) either spend little time in freshwater or spend it in riverine environments that are not likely to be highly affected by marine-derived nutrients. Although nutrients can be stored in fluvial environments in the hyporheic zone or in streamside vegetation (Helfield 2002), the large size of these watersheds and of the area that they drain suggests that the input of nutrients from salmon carcasses might not be significant relative to inputs from other sources (e.g., alder (Helfield 2002, Volk et al. 2003)). Finally, there is little in the record of escapement to these stocks to suggest that there was a period of low escapements (i.e., low nutrient input) immediately proceeding the reductions in productivity they experienced.

6 Comparing life history models with stock-recruitment models to assess salmon escapement goals – R. Lessard

A life-history modeling approach was evaluated for its usefulness in setting escapement goals for AYK stocks given limited availability of brood table data as well as age composition data. We examined stocks for which brood table data exist, and focused on the stocks with the longest time series. We compared life-history models with traditional stock recruitment curve fitting (Beverton-Holt and Ricker) approaches to escapement goal analysis.

We statistically fit models to brood-year return data of Andreafsky, Kwiniuk and Anvik chum stocks. We present life history parameter estimates of fry production capacities, fry survival, spawning migration rates, and survival rates of adults in the ocean. For comparison, we also provide estimates of Beverton-Holt and Ricker productivity (*a* parameter) and carrying capacity (density dependent *b* parameter). For both the traditional stock recruitment approach and life history model (LHM) approach, we calculate three quantities relevant to the management of the stock: 1) the constant harvest rate (or exploitation rate), 2) the fixed escapement, and 3) the resulting yield. We also present alternative perspectives that are obtained from the LHM analyses. These include fitting LHMs with survival rates that vary from year to year, searching for policies that harvest a constant proportion of the run after a minimum escapement has been reached, and looking for feedback relationships to determine exploitation rates at different run sizes.

Methods

We constructed a generic life history model that mimics the life history of a salmon population that spawns, produces fry with a density dependent relationship, has a probability of smolting within a specified number of years, and later has a probability of migrating back from the ocean to spawn between some minimum and maximum number of years. We used the approach in *Lessard et al. (2007)*, modifying the sockeye specific life history to accommodate for any number of years of residency in fresh water or in the ocean. The model recruits fish from one life history stage to another, distributing siblings across years depending on migration rates and survival rates. We model ocean survival such that the probability of surviving the final year in the ocean is always greater than the preceding years. The model is not specific to chum. It can also be used to assess chinook, sockeye or pink salmon, as long as the input files contain the required lower and upper limits on the number of years in fresh water and ocean. For example, the chum stocks analyzed herein smolt the year following spawning and remain in the ocean between 2 and 5 years. This implies that the only fresh water survival rate is survival from egg to fry, but there are four ocean survival rates, and 3 smolt migration rates (probabilities of migrating after two, three or four years, with the fifth year migration being the balance of the total probability of migration in any of the years).

We estimated life history rates by fitting the model to empirically observed catch and escapement data (NB: catch and escapement in some cases were reconstructed from estimated allocations between commercial and subsistence catches). With estimated life history rates, we used an algorithm to compute the optimal constant harvest rate U_{MSY} and the fixed escapement S_{MSY} policies that would result in the highest long term yield. Similarly, we estimated the Beverton-Holt and Ricker *a* and *b* parameters and calculated U_{MSY} and S_{MSY} that those models predicted.

Results

We used the estimated rates from three variations on the life history model:

1. The constant rate (CR) model where survival rates are the same every year
2. A variable rate (VR) model where survival rates vary from year to year
3. A variable rate model with inter-annual variation constrained (VRc) to vary within a fixed range of variation.

A comparison of the policies that arise from statistically fitting traditional stock-recruitment models and the CR model is presented in Table 1 for each of the systems. Plots of the statistical fits of all the models to the spawner/recruit data are shown in Figure 1.

Plots of model fitting visually show that all models fit the data about as well, but that the LHM curve seems a bit steeper at the origin. As a result, the life history model estimates higher productivity at low spawner abundances than do the BH and Ricker models. Additionally, the life history model analysis calls for higher exploitation rates and lower escapements. Furthermore, LHM analysis predicts about 30-40% higher yield. These results come from a life history model that assumes that rates do not vary over time, but an alternative view is that temporal variation in survival rates can explain some of the observed pattern, and that estimation of marine survival rates by year of ocean entry can be useful to detect trends in ocean condition.

		Andreafsky	**Kwiniuk**	**Anvik**
BH	a	4.42	7.75	5.18
	b	6.37E+02	4.58E+01	1.22E+03
	S_{MSY}	1.59E+05	1.05E+04	3.01E+05
	U_{MSY}	0.52	0.64	0.56
	Yield	1.75E+05	1.88E+04	3.84E+05
Ricker	a	2.93	3.53	2.85
	b	2.17E-03	3.15E-02	1.03E-03
	S_{MSY}	2.11E+05	1.65E+04	4.34E+05
	U_{MSY}	0.46	0.52	0.45
	Yield	1.81E+05	1.81E+04	3.57E+05
CR	S_{MSY}	1.02E+05	1.24E+04	2.91E+05
	Yield	2.52E+05	2.12E+04	4.57E+05
	U_{MSY}	0.76	0.69	0.66
	Yield	2.53E+05	2.13E+04	4.51E+05

Table 1: Summary of estimated parameters and derived policy variables.

An additional analysis involved estimating the demographic rates and using those rates to search for flexible policies that set minimum escapements after which a constant exploitation rate is implemented. We applied this general policy (GP) rule to the CR and VR models. Figure 2 shows the predicted yields across a range of policy combinations when survival rates are allowed to vary in time with a given constraint on inter-annual variation expressed as a coefficient of variation (CV) between 0 and 0.2 (0 being the CR model). Allowing the survival rate estimates to vary over time is analogous to reconstructing the population dynamics with a hind-cast of the rates and looking for policies that optimize total yield given the fluctuations in survival rates. Figure 2 shows the yield that would have been obtained had a given policy been implemented under the conditions predicted using the respective models. The contour plots inherently contain the estimated yields at S_{MSY} and U_{MSY} , with the profile of yields at the MSY policies showing up as gradients along one of the axes. At zero minimum escapement, the gradient of contours along the y-axis represent the profile of yields across a range of U_{MSY}. At a harvest rate of 1.0, reading horizontally along the top of each contour plot, the contours show the gradient of yields observed at S_{MSY}. The contours thus show the general pattern of the yield that is achievable using a range of policy options. Most notably, we see that a range of yields are obtainable with a variety of combinations of minimum escapement and exploitation. Visually, this is seen as an upward sloping ellipsis, where higher minimum escapements are accompanied by higher exploitation rates.

Using the rate estimates to further explore the best policies that would maximize yield is analogous to acting as though management could be implemented as though it had the foresight of what the survival rates would be; in effect predicting future anomalies. The result is that the predicted yields (and policies that produce them) capture a reflection of natural variation that is not possible in reality. Nonetheless, searching for policies that are robust to this variation shows us what the potential yield could have been.

Given the estimates of time varying survival rates, we further explored the potential for forecasting population dynamics under a hypothetical scenario where it is assumed that management has knowledge of future survival rates and will update harvest rates on a yearly basis to take advantage of this knowledge. This differs from the GP rule by changing the rules each year to take advantage of known future conditions, whereas the GP rule did not change tactics on a yearly basis. We simulate the population trends when estimated harvest rates are applied to adult returns. Simulating forward in time shows us the effect of allowing more spawners to escape when upcoming survival rates are expected to be high. This has the effect of projecting high abundances since management always takes advantage of upcoming “good years”. The interesting result that emerges is that the predicted harvest rates can be plotted across the range of adult return abundances, showing how the predicted harvest rate changes with abundance. This acts as a feedback policy where the target harvest rate on the y-axis roughly follows an increasing pattern with higher return abundances. In Figure 3, we show both the empirical harvest rates at observed return abundances and the estimated harvest rates at predicted abundances. We see that historical harvest rates varied from 20% to 80%, but the stock was harvested at those same rates at much lower spawner densities than the equivalent forecasted scenario. In the survival-forecasted (SF) scenario, the stock is built up to higher densities by keeping harvest rates low and it is then exploited more intensely when spawner densities are built up. The pattern is partially influenced by predicted future survival rates and partially influenced by the fact that the optimal policy is chosen such that total catch is highest with the exploitation rate scheme, even if it means building up the stock for complete exploitation at the end of the period over which the management actions were simulated. The main conclusion to be drawn from this is that the Andreafsky and Kwiniuk stocks were historically harvested at high exploitation rates at much lower run sizes than the SF analysis would have chosen. The SF analysis would have allowed the stocks to build during highly productive years and then subsequently fished the stocks down as survival productivity began to decline.

Discussion

We have tested the usefulness of using LHM's to establish escapement goals in AYK chum stocks and we assume that our findings also apply to chinook stocks. We base this assumption on the fact that stocks have similar life history complexities from the perspective of modeling and parameter estimation. We find that the LHM's show similar results to traditional stock recruitment models, with the exception that they predict optimal yields at slightly lower escapements. We attribute this result to the fact that the explicit estimation of survival at ocean age disaggregates some of the variation that could otherwise be attributable to density dependence in egg survival (a biological phenomenon less estimable when brood year returns are aggregated). We caution however, that this result should be further investigated using data that is

Annual survival rates were estimated in this analysis primarily to reconstruct historical survival trends and examine the policy implications in a retrospective framework. The basic structure of the VR model has some benefits that warrant further investigation: 1) estimated survival rate trends can be used to forecast abundance of future returning age classes from cohorts that had sibling returns in the current year and 2) when visualizing the yield contours, it provides an indication of the relative tradeoff between U_{MSY} and S_{MSY} policies that comes from knowing the trend in survival. That knowledge, when visualized with generic policy options, seems to tend away from constant harvest rate policies toward fixed escapement policies (Figure 2). Plots of the optimal retrospective exploitation rates against run sizes (Figure3) confirm this. informative to ocean survival rates.

Whereas our initial motivation for pursuing this research was based on successful attempts at reconstructing Bristol Bay sockeye populations, we find that having only a single freshwater age class, the chum stocks analyzed here did not exhibit sufficient age structure so that the model fitting could effectively estimate the number of parameters in the LHMs. Analyses of Bristol Bay sockeye did not exhibit this problem because the complex age structures (2 fresh and 2 ocean ages) made it plausible for the statistical fitting procedures to distinguish between freshwater and ocean survival owing to the fact that the divergent age class returns could only be explained by a limited number of combinations of parameter values. In other words, age class structure contains information about demographic rates not directly obvious from the number of recruits per spawner alone. The single-freshwater age of the chum stocks did not provide this additional hidden statistical information. It should also be noted that in previous Bristol Bay analyses, the same analyses were not plausible when brood tables were under roughly 20 years in length, which is the range of time series lengths of chum stocks analyzed here. The main limitations to applying the LHM method to escapement goal analysis in the AYK region are 1) the time series of spawner recruit data are brief, and 2) that the chum and Chinook stocks lack age structure.

We suggest a possible solution to this problem. In the absence of long time series, and in light of the fact that simple age structure of the AYK stocks limits the ability to estimate demographic rates, the analysis needs to be augmented with additional information that can help estimate survival rates. A possibility is to include growth/survival relationships into the current statistical estimation procedures. This would involve implementing additional statistical fitting procedures into the current framework. We suggest that where growth and survival can be inferred from ASL or scale data (Ruggerone *et al.* 2005), additional insights could be brought to bear on the survival estimates, possibly further explaining the source of variation in survival, and ultimately getting a better idea of density dependent survival rates. Specifically, it would help to identify not only the distinction between variation in fresh and ocean survival, but also yearly variation in ocean survival.

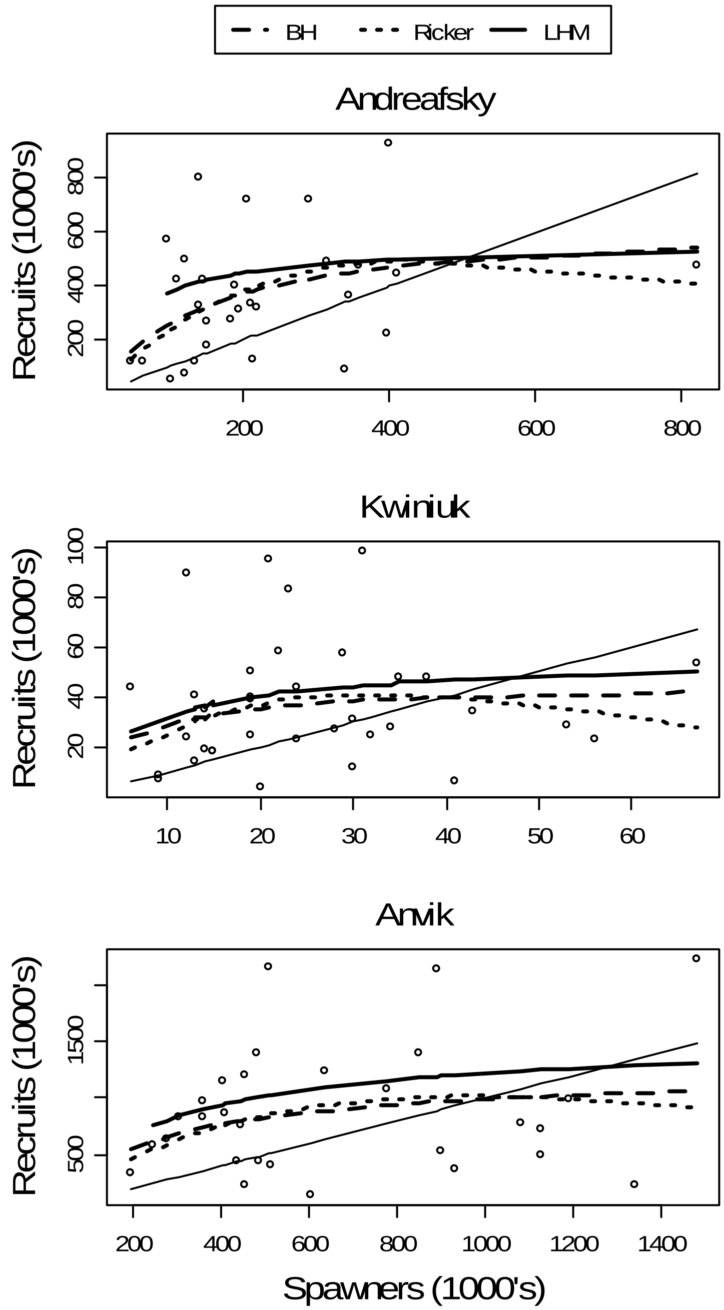


Figure 1: Stock recruitment fit of three models to the Andreafsky. Circles are the total adult returns observed at a given spawning biomass. Thick lines are the statistical maximum likelihood fits of models to data. Thin solid line represents the 1:1 replacement line. Maximum sustained yield can be visualized at the spawning biomass where the maximum difference occurs between the estimated recruitment and the 1:1 replacement line.

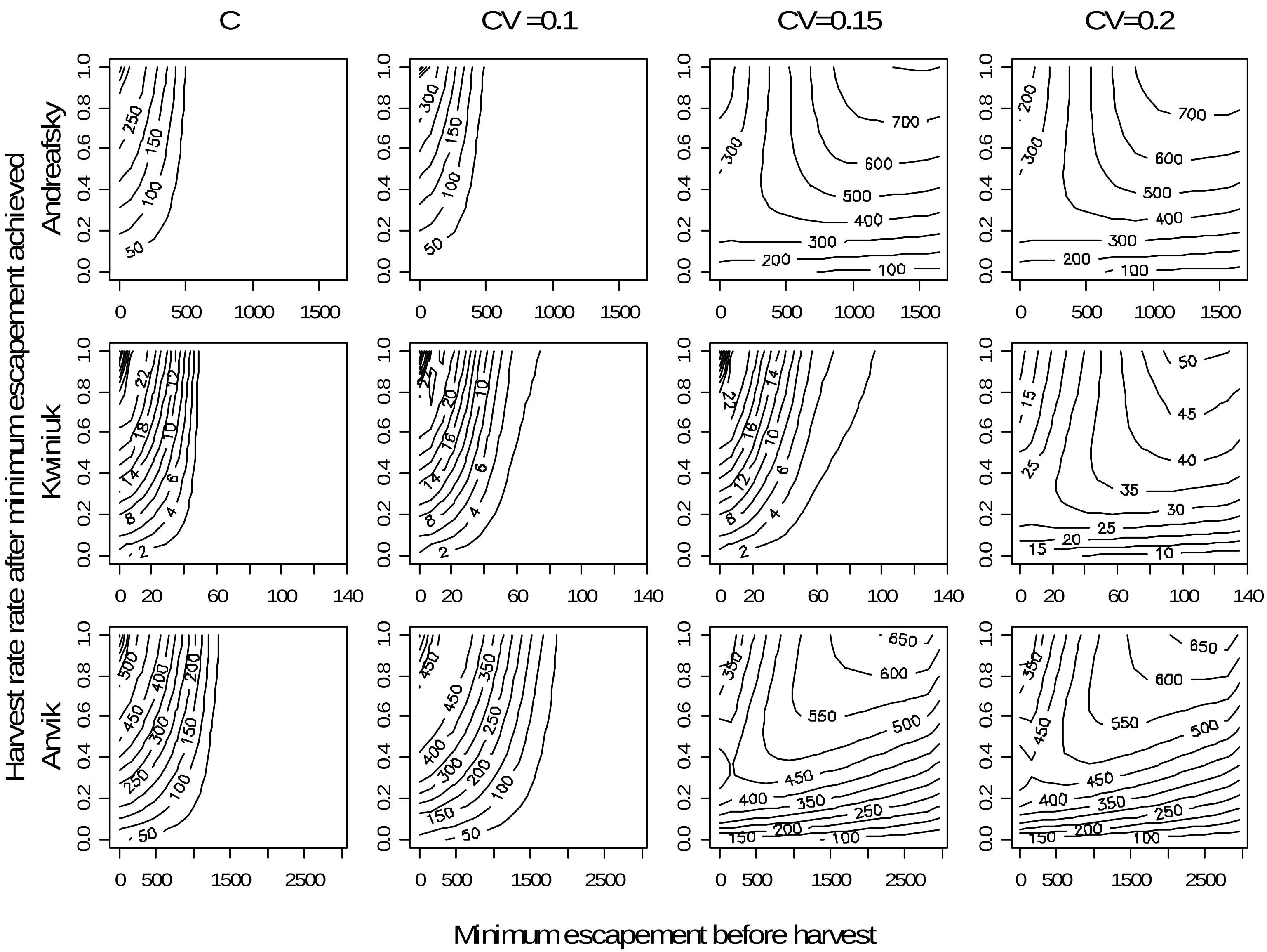


Figure 2: Contour plots of predicted yield for generic policy options. Contour lines represent the yield in thousands that is predicted when minimum number of fish is allowed to escape (x-axis) and a constant portion (y-axis) is harvest thereafter.

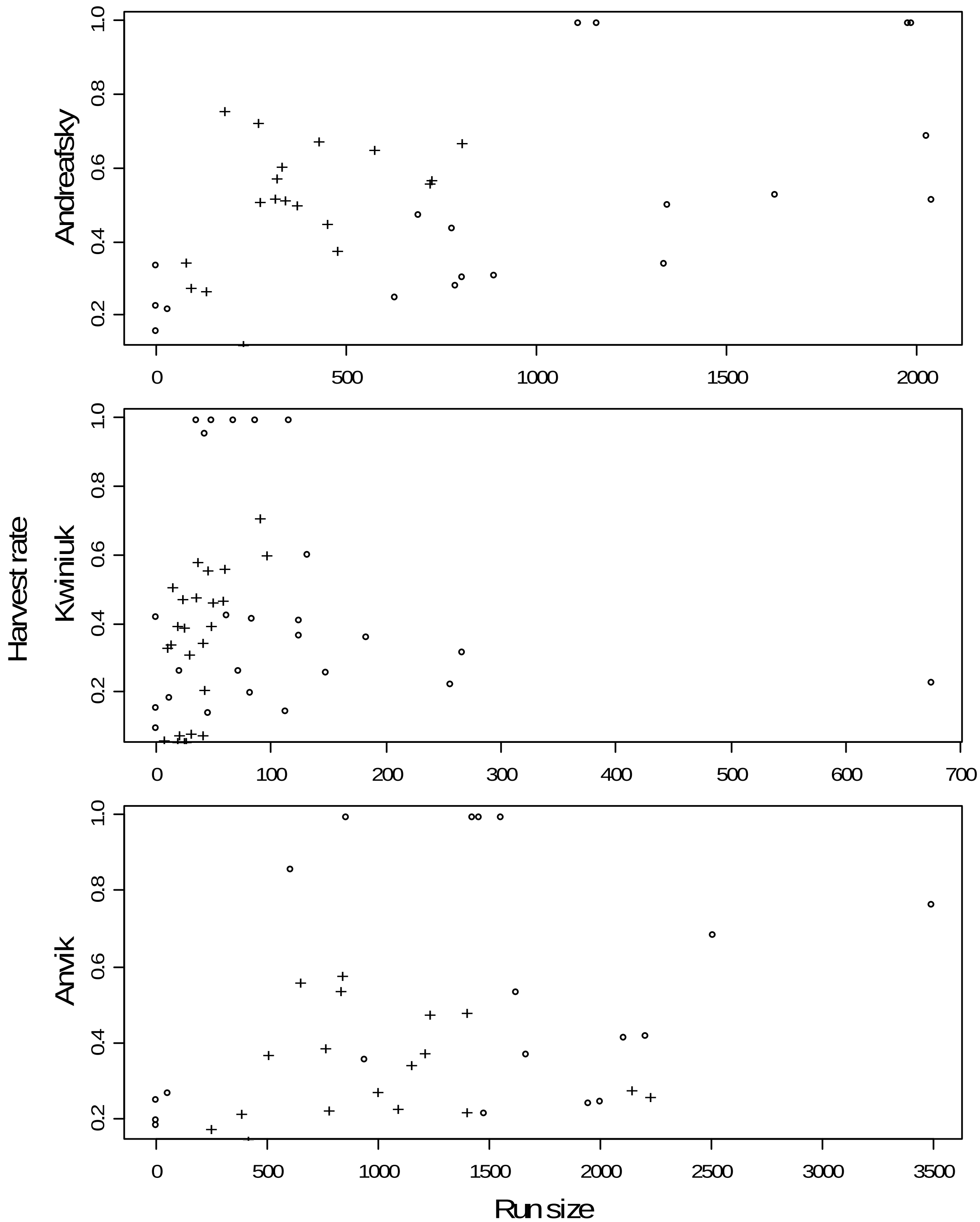


Figure 3: Estimated harvest rate as a function of run size. Circles represent estimated harvest rates to achieve maximum yield at predicted run sizes. Crosses represent observed harvest rates at observed run sizes.

7 Estimating Juvenile Chum populations for the Andreafsky, Kwinuik, and Anvik Rivers – J. Stanford and D. Whited

The Flathead Lake Biological Station has operated a field camp on the Kwethluk River in southwest Alaska since 2004 to collect a suite of biological and physical attributes that relate to riverine salmon productivity. Data were obtained during May through October annually to assess the habitat complexity in relation to distribution and abundance of salmon fry in the river system. Juvenile salmon data by habitat type are obtained using a routine electro-fishing sampling protocol. Juvenile density and growth data are coupled with aerial extent of habitats as determined from satellite imagery. This allows estimation of juvenile fish abundance and productivity throughout each study reach of the river. We are attempting to collect data from enough river reaches to enable whole river estimation of salmon productivity. Herein we present preliminary findings for the Kwethluk River and we use these data to provide a rough estimate for Andreafsky, Kwinuik and Anvik chum salmon populations, assuming, of course, that productivity of these populations is similar to the Kwethluk. That is, we estimated the habitat area for the rivers in question and used Kwethluk chum data to provide a ball park estimate of what might be possible for the rivers where chum salmon density data were available.

Estimation of Juvenile Chum Populations in the Kwethluk

Electro-fishing of juvenile fish in main channel shallow shore (MCSS), parafluvial springbrook (PFSB), and orthofluvial springbrook (OFSB) habitats were conducted on the Kwethluk River in the summer of 2005 and 2006. Juvenile chum salmon were present in samples collected between May 30th and June 22nd. Juvenile chum density (Table 1) was calculated for the three key habitats from the data collected.

Habitat Type	Juvenile chum density (fish per m^2)
MCSS	0.168564246
PFSB	0.041576248
OFSB	0.317369616

Table 1. Juvenile chum density by habitat type

However, chum salmon are well documented to out-migrate (smoltify) fairly early in the season (Salo 1991) and we estimate that we sampled only the last quarter of the chum out-migration based on the frequency of occurrence of chums in our samples and direct observation of the timing of swim-up from the redds. Therefore, we accounted for this early out-migration by increasing field densities estimates by a factor of four.

To estimate the total number of juvenile chum found in the Kwethluk study reaches, the density per habitat type were multiplied by the amount of area of each habitat type (Table 2) identified from satellite imagery acquired in the summer of 2004.

Habitat Type	Habitat Area (sq m)	% of Habitat Type
MCSS	623301	0.43
PFSB	239714	0.17
OFSB	590886	0.41

Table 2. Amount of habitat area and relative proportion of each habitat type

For the Kwethluk study reach, 1,210,248 juvenile chums were estimated to occupy this floodplain reach during the sampling period. To scale the estimates of the juvenile chum populations up to entire Kwethluk river system, we estimated the number of fish per sq km (44,824) of our primary study reaches (27 sq km, total). The number of fish per sq km was then divided into the relative proportion of habitat types (Table 2) per sq km to estimate the relative number of fish per habitat type per sq km (Table 3). These chum densities were then multiplied by total floodplain area to estimate juvenile chum populations for the three key habitats throughout the river.

Habitat Type	Estimated # of juv. fish per sq km of floodplain
MCSS	19217
PFSB	7390
OFSB	18217

Table 3. Estimated number of juvenile chum per habitat type per square km

Estimating chum populations for the Andreafsky, Kwinuik, and Anvik Rivers

Using the estimate of juvenile chum populations from the Kwethluk River, juvenile chum populations were extrapolated to the Andreafsky, Kwinuik, and Anvik Rivers based on the amount of floodplain area identified along these river systems using FLBS satellite imagery analyses. Floodplain areas were calculated for the three river systems using Landsat imagery and 90 m SRTM Digital Elevation Model (DEM). Drainage features were extracted from Landsat imagery and used to model the extent of floodplains within each river system. Juvenile chum populations for each river system (Table 3) were then estimated by multiplying floodplain area by the number juvenile chum per sq km for each habitat type.

River	Floodplain Area (sq km)	# of chum MCSS	# of chum PFSB	# of chum OFSB
Andreafsky	79	1518101	583844	1439151
Kwiniuk	20	384329	147809	364342
Anvik	254	4880982	1877170	4627144

Table 4. Estimated chum salmon densities prior to outmigration for the Andreafsky, Kwiniuk and Anvik Rivers, Alaska, based on extrapolation of Kwethluk River data.

Discussion

This analysis is intended as a first cut at linking the remote (satellite) estimation of total habitat to on-the-ground estimates of fry density. We realize that the bounds on the estimates likely are large. But, hopefully this approach provides a rough validation check for modelers studying stock-recruitment relationships. We are collecting additional data on the Kwethluk in 2007, coupled with outmigration data collected with inclined plane traps by the USGS, Alaska Science Center. These data will hopefully add credibility to the approach.

8 Summary

A retrospective time-series analysis of recruits per spawner revealed that all three analyzed stocks exhibited a strong downward long term trend in density- corrected recruits per spawner; and the strong year effects after correcting for both the trend and density show strong driving by some regional factor that affects all three stocks more or less synchronously. A life-history model analysis of recruitment over time showed that constant harvest rate policies are optimal when variation in productivity over time is not considered, but that as variation in survival rates is considered, optimal policies tend toward fixed escapements. This is exemplified by a retrospective analysis where optimal harvest rates would have been low in earlier years to take advantage of the most productive years. Overall, we concluded that productivity generally declined, but no distinction between freshwater and ocean survival could be attributed to cause. We note that a more detailed exploration of these trends would be possible through a more complex analysis involving survival rate estimation in conjunction with growth rates.

Selected References

ADF&G (Alaska Department of Fish and Game). 2001. Annual management report Yukon area, 2000. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A02-29, Anchorage.

Apodaca, C.K., and D.W. Daum. 2005. Estimated abundance of adult fall chum salmon in the middle Yukon River, Alaska, 2004. U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report Number 85, Fairbanks.

Busher, W.H., and T. Hamazaki. 2005. Subsistence and personal use salmon harvests in the Alaska portion of the Yukon River Drainage, 2003. Alaska Department of Fish and Game, Division of Commercial Fisheres, Regional Information Report No. 3A04-33, Anchorage.

Clark, J.H. 2001a. Biological escapement goals for Andreafsky River chum salmon. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A01-07, Anchorage.

Clark, J.H. 2001b. Biological escapement goal for chum salmon in subdistrict one of Norton Sound. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A01-09, Anchorage.

Clark, J.H., and G.J. Sandone. 2001. Biological escapement goal for Anvik River chum salmon. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A01-06, Anchorage.

Cleary. P.M., and T. Hamazaki. 2005. Fall chum salmon mark-recapture abundance estimation on the Tanana and Kantishna Rivers, 2004. Alaska Department of Fish and Game, Fishery Data Series No. 05-76, Anchorage.

DeCicco, F. 2004. Fishery management report for sport fisheries in the northwest Alaska management area, 2002-2003. Alaska Department of Fish and Game, Fishery Management Report No. 04-01, Anchorage.

Doxey, M. 2004. Salmon studies in the Chena, Chatanika, Delta Clearwater, and Salcha rivers, 2002 and 2001. Alaska Department of Fish and Game, Fishery Data Series No. 04-01, Anchorage.

Doxey, M., A. Brase, and D. Reed. 2005. Salmon studies in the Chena, Chatanika, Delta Clearwater, and Salcha rivers, 2002 and 2003. Alaska Department of Fish and Game, Fishery Data Series No. 05-65, Anchorage.

DuBois, L. 2005. Origins of Chinook salmon in the Yukon River fisheries, 2003. Alaska Department of Fish and Game, Fishery Data Series No. 05-46, Anchorage.

Dunbar, R., and C.T. Pfisterer. 2004. Sonar estimation of fall chum salmon abundance in the Sheenjek River, 2002. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A04-10, Anchorage.

Eggers, D.M. 2001. Biological escapement goals for Yukon River fall chum salmon. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A01-10, Anchorage.

Evenson, M. 1993. Abundance, egg production, and age-sex-length composition of the Chinook salmon escapement in the Chena River, 1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-6, Anchorage.

Evenson, M. 1995. Salmon studies in interior Alaska, 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-5, Anchorage.

Evenson, M. 1996. Salmon studies in interior Alaska, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-17, Anchorage.

Evenson, M. 2002. Optimal production of Chinook salmon from the Chena and Salcha rivers. Alaska Department of Fish and Game, Fishery Manuscript Series No. 02-01, Anchorage.

Evenson, M., and L. Stuby. 1997. Salmon studies in interior Alaska, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 97-31, Anchorage.

Gende, S. M., R. T. Edwards, M. F. Willson, and M. S. Wipfli. 2002. Pacific Salmon in Aquatic and Terrestrial Ecosystems. Bioscience **52**:917-928.

Gewin, C. 2005. Abundance and run timing of adult Pacific salmon in the East Fork Andreafsky River, Yukon Delta National Wildlife Refuge, Alaska, 2004. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2005-13, Fairbanks.

Gewin, C. and G. VanHatten. 2005. Abundance and run timing of adult Pacific salmon in the East Fork Andreafsky River, Yukon Delta National Wildlife Refuge, Alaska, 2003. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2005-10, Fairbanks.

Gordon, J.A., S.P. Klosiewski, T.J. Underwood, and R.J. Brown. 1998. Estimated abundance of adult fall chum salmon in the upper Yukon River, Alaska, 1996. U.S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Technical Report Number 45, Fairbanks.

Hamazaki, T. 2003. Kwiniuk River salmon counting tower project review and variance estimation. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A03-20, Anchorage.

Harper, K. and Waltry, C. 2001. Abundance and run timing of adult salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 2000. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2001-4, Kenai.

Hartman, W. L., and R. L. Burgner. 1972. Limnology and fish ecology of sockeye salmon nursery lakes of the world. J. Fish. Res. Board Can **29**:699-715.

Helfield, J. M. 2002. Interactions of salmon, bear and riparian vegetation in Alaska. Dissertation. University of Washington, Seattle, WA.

Helfield, J. M., and R. J. Naiman. 2006. Keystone interactions: Salmon and bear in riparian forests of alaska. Ecosystems **9**:167-180.

JTC (Joint Technical Committee of the Yukon River US/Canda Panel). 2006. Yukon River salmon 2005 season summary and 2006 season outlook. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A06-03, Anchorae.

Kent, S. 2006. Salmonid escapements at Kwiniuk, Niukluk and Nome Rivers, 2005. Alaska Department of Fish and Game, Fishery Data Series No. 06-22, Anchorage.

Knudsen, E.E. 2000. Managing Pacific salmon escapements: the gaps between theory and reality. Pages 237-272 *in* E.E. Knudsen and four co-editors. Sustainable Fisheries Management: Pacific Salmon, Lewis Publishers, Boca Raton, Florida.

Kohler, T. and G. Knuepfer. 2001a. Kwiniuk River salmon counting tower project, 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A02-12, Anchorage.

Kohler, T. and G. Knuepfer. 2001b. Nome River salmon counting weir project, 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Informational Report RIR 3A02-13, Anchorage.

Kohler, T. and G. Todd. 2003. Salmonid escapements into selected Norton Sound drainages using towers and weirs, 2002. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A03-18, Anchorage.

Kohler, T. 2003. Salmonid escapements into selected Norton Sound drainages using towers and weirs, 2003. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A03-33, Anchorage.

Kohler, T., A. Banducci, J. Soong, J. Menard. 2005. Annual management report, 2004; Norton Sound-Port Clarence-Kotzebue. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A05-04, Anchorage.

Lessard, R. B., R. Hilborn, B. Chasco. 2006. (*submitted manuscript*) Escapement goal analysis and stock reconstruction of sockeye salmon populations (*Oncorhynchus nerka*) using life-history models.

Mathisen, O. A. 1971. Escapement levels and productivity of the Nushagak sockeye salmon run from 1908 to 1966. Fish. Bull. Natl. Oceanic Atmos. Adm., Seattle **69**:747-763.

Mathisen, O. A., and P. H. Poe. 1981. Sockeye Salmon Cycles in the Kvichak River, Bristol Bay, Alaska. SCHWEIZERBARTSCHE VERLAGSBUCHHANDLUNG, STUTTGART (FRG).

Willson, M. F., and K. C. Halupka. 1995. Anadromous Fish as Keystone Species in Vertebrate Communities. Conservation Biology **9**:489-497.

McEwen, M. 2006a. Anvik River sonar chum salmon escapement study, 2004. Alaska Department of Fish and Game, fishery Data Series No. 06-42, Anchorage.

McEwen, M. 2006b. Anvik River sonar chum salmon escapement study, 2005. Alaska Department of Fish and Game, fishery Data Series No. 06-43, Anchorage.

Menard, J. and D. Bergstrom. 2003. Norton Sound Golovin and Moses Point subdistricts; chum salmon stock status and action plan. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 3A03-36, Anchorage.

Menard, J. and S. Kent. 2005. Salmonid escapements at Kwiniuk, Niukluk and Nome Rivers, 2004. Alaska Department of Fish and Game, Fishery Data Series No. 05-24, Anchorage.

Osborn, B.M., abd J.L. Melegari. 2002. Use of split-beam sonar to enumerate Chandalar River fall chum salmon, 2000. U.S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Technical Report Number 61, Fairbanks.

Roettiger, T., K. Harper, and A. Chikowski. 2002. Abundance and run timing of adult salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 2001. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2002-8, Kenai.

Roettiger, T., K. Harper, and D. Nolfi. 2003. Abundance and run timing of adult salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 2002. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2003-6, Kenai.

Roettiger, T., F. Harris, and K. Harper. 2004. Abundance and run timing of adult salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 2003. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2004-8, Kenai.

Roettiger, T., F. Harris, and K. Harper. 2005. Abundance and run timing of adult salmon in the Kwethluk River, Yukon Delta National Wildlife Refuge, Alaska, 2004. U.S. Fish and Wildlife Service, Alaska Fisheries Data Series Number 2005-7, Kenai.

Ruggerone, G.T., Farley, E., Nielsen, J. and Hagen, P. 2005. Seasonal marine growth of Bristol Bay sockeye salmon (Onchorynchus nerka) in relation to competition with Asian pink salmon (O. gorbuscha) and the 1977 ocean regime shift. Fish. Bull. 103:355-370.

Salo, E.O. 1991. Life history of Chum Salmon (*Oncorhynchus keta*). Pages 231–310 *in* C. Groot and L. Margolis, editors. Pacific Salmon Life Histories. Univ. of British Columbia Press, Vancouver.

Schmidt, D. C., S. R. Carlson, G. B. Kyle, and B. P. Finney. 1998. Influence of Carcass-Derived Nutrients on Sockeye Salmon Productivity of Karluk Lake, Alaska: Importance in the Assessment of an Escapement Goal. North American Journal of Fisheries Management **18**:743-763.

Skaugstad, C. 1994. Salmon studies in interior Alaska, 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-14, Anchorage.

Stockner, J. G. 2003. Nutrients in salmonid ecosystems: sustaining production and biodiversity., Bethesda, Maryland.

Stockner, J. G., and K. I. Ashley. 2003. Salmon Nutrients: Closing the Circle. American Fisheries Society, 5410 Grosvenor Ln. Ste. 110 Bethesda MD 20814-2199 , [URL http //afs.allenpress.com].

Stuby, L. 1999. Salmon studies in interior Alaska, 1998. Alaska Department of Fish and Game, Fishery Data Series No. 99-13, Anchorage.

Stuby, L. 2000. Salmon studies in the Chena, Chatanika, and Delta Clearwater rivers, 1999. Alaska Department of Fish and Game, Fishery Data Series No. 00-4, Anchorage.

Stuby, L. 2001. Salmon studies in interior Alaska, 2000. Alaska Department of Fish and Game, Fishery Data Series No. 01-24, Anchorage.

Stuby, L., and M. Evenson. 1998. Salmon studies in interior Alaska, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-11, Anchorage.

Tobin, J., and K. Harper. 1998. Abundance and run timing of adult salmon in the East Fork Andreafsky River, Yukon Delta National Wildlife Refuge, Alaska, 1997. US Fish and Wildlife Service, Alaska Fisheries Data Series Number 98-2, Kenai.

Tobin, J., and K. Harper. 1999. Abundance and run timing of adult salmon in the East Fork Andreafsky River, Yukon Delta National Wildlife Refuge, Alaska, 1998. US Fish and Wildlife Service, Alaska Fisheries Data Series Number 99-3, Kenai.

Uchiyama, T. 2007. Effects of marine-derived nutrients on population dynamics of sockeye salmon (Oncorhynchus nerka). M.S. Thesis, University of Alaska Fairbanks.

Underwood, T.J., and J.F. Bromaghin. 2003. Estimated abundance of adult fall chum salmon in the middle Yukon River, Alaska, 2000-2001. U.S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Technical Report Number 62, Fairbanks.

Underwood, T.J., J.F. Bromaghin, and S.P. Klosiewski. 2002 Evidence of handling mortality in fall chum salmon caused by fish wheel capture on the Yukon River, Alaska. U.S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Technical Report Number 59, Fairbanks.

Underwood T.J., S.P. Klosiewski, J.L. Melegari, and R.J. Brown. 2000. Estimated abundance of adult fall chum salmon in the middle Yukon River, Alaska, 1998-1999. U.S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Technical Report Number 57, Fairbanks.

Underwood T.J., S.P. Klosiewski, J.A. Gordon, J.L. Melegari, and R.J. Brown. 2000. Estimated abundance of adult fall chum salmon in the upper Yukon River, Alaska, 1997. U.S. Fish and Wildlife Service, Fishery Resource Office, Alaska Fisheries Technical Report Number 56, Fairbanks.

Volk, C. J., P. M. Kiffney, and R. L. Edmonds. 2003. Role of Riparian Red Alder in the Nutrient Dynamics of Coastal Streams of the Olympic Peninsula, Washington, USA. American Fisheries Society, 5410 Grosvenor Ln. Ste. 110 Bethesda MD 20814-2199 , [URL http //afs.allenpress.com].

Willson, M. F., and K. C. Halupka. 1995. Anadromous Fish as Keystone Species in Vertebrate Communities. Conservation Biology **9**:489-497.

Wuttig, K. 1999. Escapement of Chinook salmon in the Unalakleet River in 1998. Alaska Department of Fish and Game, Fishery Data Series No. 99-10, Anchorage.

Zabkar, L., and K. Harper. 2003. Abundance and run timing of adult pacific salmon in the East Fork Andreafsky River, Yukon Delta National Wildlife Refuge, Alaska, 2001 and 2002. US Fish and Wildlife Service, Alaska Fisheries Data Series Number 2003-5, Kenai.