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Area 3, 4, 5 Pink and Chum Exploitation Rate Model

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

A large amount of time and resources are expended each year by Fisheries and Oceans Canada (DFO), Pacific Salmon Commission (PSC), First Nations, stewardship groups, Pacific Salmon Foundation (PSF) and other NGOs to obtain the catch and escapement data needed to monitor trends for BC salmon stocks and Conservation Units (CUs). A large portion of these data are available in DFO databases (e.g. NuSEDS and FOS). For many North and Central Coast (NCC) salmon stocks, these data have been combined in models to derive estimates of run size and exploitation rates for specific salmon indicator stocks (Alexander et al. 2010, English et al. 2016). The purpose of the report is to provide more comprehensive documentation for the Area 3-5 Pink and Chum Model previously described in English et al. (2012; 2014; 2016) and the recent enhancements made to re-program and streamline the data updating process for this model using R code.

The primary purpose of the Area 3-5 Pink and Chum Model is to estimate annual exploitation rates (ERs) for Pink and Chum salmon stocks returning to streams within Areas 3, 4 and 5. This model is not designed to estimate ERs by CU but estimate ERs that could be used to estimate the annual catch for each of the CUs with streams in Areas 3, 4 and/or 5. The 2018 report for NCC salmon escapement, catch, run size and exploitation rates for each salmon CU provides tables that list all Pink and Chum salmon CUs and their associated Area and ERs (see Table 3 and 4 in English et al. 2018).

In 2018, LGL Limited was contracted by PSF to work with DFO stock assessment biologists to update the core datasets, database systems and analysis tools needed to track stock status and trends for NCC salmon stocks using the best available information from 1954-2017. This report is part of a project that builds on previous work supported by Indian and Northern Affairs Canada (INAC), the State of the Salmon Program (SOS), DFO, and PSF to produce the 1980-2010 estimates of escapement, catch and run size for BC Salmon (English et al. 2004a; 2006a; b). In 2005-06, a comprehensive review of the North and Central Coast (NCC) salmon stock assessment programs was conducted and the indicator streams were identified for each salmon species (English et al. 2006). In 2008-09 the SOS Program, DFO and PSF supported additional efforts to compute these estimates for each BC Salmon CU (English et al. 2010). As part of this project, the NCC Salmon Database and Analysis System was developed using MS Access to house all the catch and escapement estimates for NCC Statistical Areas (Areas) and CUs, as well as the best available estimates of the exploitation rates for each salmon species by Areas and, where possible, by CU. In 2011-12, the PSF supported projects to update the NCC Database and Analysis System and the various models used to compute annual exploitation rates for NCC salmon (English et al. 2012). In 2013, catch, escapement and exploitation rate estimates for 1954-1979 were added to the analyses for Skeena Salmon CUs (English et al. 2013) and in 2014-15 similar work was done to extend the time-series for most NCC CUs back to 1954 and up to 2014 (English et al. 2016).

Analysis Objectives

The Pink and Chum Model estimates exploitation rates for Pink and Chum salmon in Area 3, Area 4 and Area 5 using a combination of historical and current catch and effort data from the BC Hail database, harvest and exploitation rates estimated from the 1982-1995 Pink Salmon Run Reconstruction (PSRR) analysis (Gazey and English 2000) and Chum Salmon harvest rates determined from the Chum Model (English et al. 2016). The analysis can be broken down into three epochs, the period before the run reconstruction analysis (i.e., 1954-1981), the years within the PSRR analysis (i.e., 1982-1995) and the period after the PSRR analysis. The PSRR analysis was built using unique information obtained in 1982, 1984 and 1985 on the contribution of Canadian and Alaskan Pink salmon stocks to Northern Boundary Area fisheries obtained throughout the international salmon tagging programs conducted in 1982, 1984 and 1985 (English et al. 1985). These data were used to build a comprehensive run-reconstruction model for Northern Boundary Sockeye and Pink salmon stocks (Gazey and English 2000). For years prior to the

PSRR analysis period, the detailed catch and escapement estimates were not available and therefore, run-reconstruction analyses were not conducted. After 1995, the data were available but there was no support to continue the run-reconstruction analyses for Northern Boundary Pink salmon stocks. Therefore, another method needed to be developed to estimate harvest rates for Pink salmon stocks in Area 3-5. In 2006, we examine the relationships between fishing effort and harvest rates for Area 3, Area 4 and District 101-104 Alaskan fisheries for the PSRR analysis years and used these relationships along with comparable annual estimates of fishing effort for years before 1982 and after 1995 to estimate Pink harvest rates. These Pink and Chum harvest rates were used estimate the corresponding exploitation rates in Area 3, Area 4, Area 5.

DATA SOURCES AND PREPARATION

Stock and Fishery Definitions

The stocks included in this model are defined by Area and include all Pink and Chum salmon populations that spawn in streams within Areas 3-5. The fisheries are also defined by Area and include all fisheries that occur in Areas 3-5. As indicated above, this model relies heavily of Effort-Harvest Rate relationships derived from the 1982-95 PSRR analyses model (Gazey and English 2000). The stock and fishery definitions for the PSRR Model were derived from the following sources: (1) management units of populations (stocks) and areas (fisheries) as defined by Department of Fisheries and Oceans (DFO) and Alaska Department of Fish and Game (ADF&G) personnel, (2) resolution of stocks and fisheries consistent with previous North Coast mark-recapture studies (Gazey et al. 1983, English et al. 1984, 1985a, Taylor et al. 1986 in B.C. and Pella et al. 1993 in Alaska). The harvest rate estimates used for Area 3 Pink salmon are those derived for the Inside Area 3 Pink salmon stock which includes all Pink salmon that originate from streams in the inner portion of Area 3 (the Kwinamass River and all streams flowing into Portland Inlet and Observatory Inlet east of the Kwinamass River, Appendix A). The definition of Canadian and Alaskan stocks and fisheries used in the PSRR analysis are provided in Gazey and English (2000; Tables 1-3).

Catch and Effort Data

Pink salmon catch and total fishing effort (boat-days) by gear type for Area 3 and 4 was extracted from the Northern Boundary Sockeye Run Reconstruction (NBSRR) database for 1982-2017 to estimate the catch per unit effort (CPUE) for gillnet and purse seine gear (Alexander et al. 2010). This database was built by LGL for the Northern Boundary Technical Committee (NBTC) with data provided by DFO and the Alaska Department of Fish and Game (ADFG). This MS Access database is housed on LGL computers and maintained under direction from the NBTC through PSC contracts with LGL. The year-specific ratios of the seine to gillnet CPUE values for were used to convert gillnet effort to seine equivalent effort for 1982-2017. The average of the CPUE ratios for 1982-2014 (i.e. one gillnet boat-day equals 0.051 of a seine boat-day) were used to convert total gillnet effort during Alaska (AK) weeks 29-36 to the purse seine equivalent effort for each year from 1954-1981. The seine equivalent effort in boat-days for 1982-1995 was used to define the Effort-Harvest Rate relationships for Areas 3 and 4. The seine equivalent effort for other years was input into the equations that defined the Effort-Harvest Rate relationship for Areas 3 and 4 to calculate the stock-specific harvest rates for 1954-1981 and 1996-2017.

Fishing effort data for Southern Southeast Alaska purse seine fisheries was also obtained from the NBSRR database and used to define the Effort-Harvest Rate relationship for these Alaskan fisheries.

The data and procedures used to prepare the catch data for the NBSRR analysis was different for Canadian and Alaskan fisheries. In Canadian gillnet and seine fisheries, the official weekly catch statistics were allocated to specific days using fisheries officer hail data. Canadian troll data were organized by week because there were no reliable estimates for daily troll catch. In Alaska, all catch data were organized by fishery openings which ranged from 1 to 7 days but tended to be 2-3 days in duration. Since the run reconstruction model operates on a daily time step and was designed to handle fisheries of varying duration the above inconsistencies in catch data were accommodated (Gazey and English, 2000).

1982-1995 Pink Run Reconstruction Analysis

The theoretical basis of run reconstruction analysis for salmon stocks and fisheries are described in Starr and Hilborn (1988) and Cave and Gazey (1994). Gazey and English (2000) provides a detailed description of the run reconstruction data sources and methods used to assess the annual returns of Sockeye and Pink salmon stocks in the Northern Boundary Area. A summary excerpt from Gazey and English 2000 is provided below:

> *"A multi-time-period method of stock reconstruction was used to estimate harvest and stock interception rates by area and time period, exploitation rates and total run size by stock. The data required for these reconstructions were catch by time and area, daily escapement by population (stock), the residence time of each population in each harvest area, and the routing of the populations. Migration routes for each stock were defined using information from the 1982-85 north coast tagging studies. The initial set of migration routing parameters were adjusted until the run reconstruction results approximated those from the tagging study years. Two different sets of migration parameters were required to fit the 1982 and 1983 interception rates for sockeye. While the 1983 set provided the best fit to the interception rates for Alaskan fisheries based on scale data for 1984-95, year to year variability can be substantial. Consequently, we incorporated all the available stock composition estimates for Alaskan fisheries into our sockeye reconstruction analysis. Limited sensitivity analysis on sockeye indicated that uncertainty in migration parameters has a greater effect on stock size estimates than interception rates. For Pink salmon, one set of migration parameters was defined that approximated the tagging study results for 1982, 1984 and 1985. Substantial changes in the annual abundance of major Pink salmon stocks appears to explain most of the variability observed in the tagging study interception rates."*

Pink run reconstruction results are available in Appendix B.

ANALYTICAL CALCULATIONS

Pink Exploitation Rates

Exploitation rates for Area 3 and 4 Pink salmon stocks in Canadian Northern Boundary commercial fisheries (Areas 1-5) were derived by combining the harvest rates estimated for Areas 1-5 commercial fisheries with the exploitation rates estimated for Area 3 and 4 Pink salmon stocks caught in Alaskan District 101-104 commercial fisheries. The Canadian Exploitation Rate (ER) represents the proportion of the total returns caught by Canadian commercial fishery was determined as:

$$ER_{a,y}^{Cdn} = \left(1 - HR_{a,y}^{Ak}\right) \cdot HR_{a,y}^{Cdn} \quad \text{for } a \in \{3,4\} \tag{1}$$

where $HR_{a,y}^{Ak}$ and $HR_{a,y}^{Cdn}$ are the Alaskan and Canadian harvest rates for a given Area (a) and year (y). The term $1 - HR_{a,y}^{Ak}$ represents proportion of the original area-specific run that remains after US interception. Multiplying the remaining proportion by Canadian harvest rates provides an estimate of the area- and year-specific Canadian exploitation rate.

Total exploitation rates for Area 3 and Area 4 Pink were then determined as the combination of Canadian and Alaskan exploitation rates:

$$ER_{a,y}^{Total} = ER_{a,y}^{Cdn} + HR_{a,y}^{Ak} \quad \text{for } a \in \{3,4\} \tag{2}$$

where the Canadian exploitation rate $\left(ER_{a,y}^{Cdn}\right)$ was estimated by Equation 1 and the Alaskan harvest rate $\left(HR_{a,y}^{Ak}\right)$ is equivalent to the Alaskan exploitation rate due to the fact the Alaskan fishery is the first fishery to intercept returning Pink salmon.

Area 5 ERs were assumed to be 50% of the estimated ERs for Area 4 Pink salmon because of a substantial portion of Area 5 Pink salmon do not migrate through fisheries in Areas 3 and 4 (Gazey and English 2000):

$$ER_{5,y}^{Cdn} = 0.5 \cdot ER_{4,y}^{Cdn} \tag{3}$$

Total exploitation rates for Area 5 were then determined by assuming US interception of Area 4 and Area 5 bound Pink salmon were roughly equal, that is,

$$ER_{5,y}^{Total} = ER_{5,y}^{Cdn} + HR_{4,y}^{Ak}. \tag{4}$$

where $HR_{4,y}^{Ak}$ is the Alaskan harvest rate for Area 4 Pink salmon and $ER_{5,y}^{Cdn}$ is the Canadian exploitation rate estimated for Area 5 (i.e., Equation 3).

Chum Exploitation Rates

Due to lack of available information historical Chum exploitation rates (i.e., 1954-1981), exploitation rates prior to 1981 were assumed to be the same as the corresponding area-specific Pink exploitation rates. From 1982 to present (i.e., 2017) area-specific exploitation rates were determined using a combination of Chum harvest rates derived from the Chum Model (English et al. 2016) and Pink harvest rates. The Canadian exploitation rates were determined by adjusting Canadian Chum harvest rates from the Chum Model for US interception based on the area-and year-specific Pink interception rates. Specifically, Canadian exploitation rates for Area 3, Area 4 and Area 5 Chum were determined as,

$$ER_{a,y,chum}^{Cdn} = \left(1 - HR_{a,y,pink}^{Ak}\right) \cdot HR_{a,y,chum}^{Cdn} \quad \text{for } a \in \{3,4,5\} \tag{5}$$

where $HR_{a,y,chum}^{Cdn}$ represents the area- and year-specific Canadian harvest rates from the Chum Model and $HR_{a,y,pink}^{Ak}$ represents the corresponding Alaskan harvest determined for Pink salmon.

Total exploitation rates were then determined using the estimate of the Canadian Chum exploitation rate (i.e., Equation 5) and the area- and year-specific Pink harvest rates to represent the proportion of the total exploitation rate made up by US interceptions. Specifically, total exploitation rates were determined as,

$$ER_{a,y,chum}^{Total} = ER_{a,y,chum}^{Cdn} + HR_{a,y,pink}^{Ak} \text{ for } a \in \{3,4,5\} \tag{6}$$

for Area 3, Area 4 and Area 5.

Pink Harvest Rates

Harvest rate estimates for Pink salmon were determined based on either direct estimates from a run reconstruction analysis (i.e., 1982-1995; Gazey and English 2000) or predicted harvest rates determined all other years (i.e., 1954-1981 and 1996-2017). Herein we use Y^{RR} to represent the run reconstruction years and Y^{ORR} to represent years outside the run reconstruction years.

Harvest rates for years outside the run reconstruction were predicted based on an effort to harvest rate relationship estimated from the 1982-1995 run reconstruction effort and harvest rates (Gazey and English 2000). Effort to harvest rate relationships were estimated as Michaelis–Menten saturation curve of the general form,

$$HR = \frac{HR_{max} \cdot E}{\left(E + E_{0.5HR_{max}}\right)} \tag{7}$$

where E represents a standardized measure of effort, HR_{max} is the maximum harvest rate that can be achieved in the system and $E_{0.5HR_{max}}$ is the effort at which the harvest rate is half of the maximum. The curve has a number of desirable properties including enforcing a harvest rate of zero when effort is zero, in addition to exhibiting saturation dynamics which reduce the relative effectiveness of each unit of effort as the overall level of effort is increased.

Two separate curves were developed to estimate harvest rates for Area 3 and 4 Pink salmon stocks based on a standardized measurement of fishing effort in Area 3 and 4 net fisheries. Area 3 and 4 fishing effort was used to predict harvest rates for fisheries in Area 3 and 4 and these were expanded to estimates of the total harvest rate for all Canadian fisheries in Areas 1-5 using the results from the 1982-1995 run reconstruction analyses.

Two separate curves were also defined to estimate exploitation rates for Area 3 and 4 Pink salmon stocks in District 101-104 Alaskan purse seine fisheries based on annual fishing effort in these fisheries in 1982-1995. For years before and after the 1982-1995 run reconstruction years, exploitation rates were estimated for these Alaskan fisheries using these curves and annual fishing effort estimates.

The HR_{max} and $E_{0.5HR_{max}}$ parameters for each curve were estimated using non-linear least squares (`nls` routine included in the R computing environment; R Core Team 2018) and confidence regions were created using a bootstrap approach.

Finally, depending on the fishery under consideration, multiple gear types may be used to harvest Pink salmon, therefore requiring a standardized measure of effort if harvest rates are to be predicted, which is specified in more detail in the following sections that explicitly define how each of the four effort to harvest rate curves were used.

Canadian Harvest Rates

For years outside the run reconstruction analysis (i.e., 1954-1981 and 1996-2017), the total harvest rate for Area 3 and 4 Pink salmon stocks in Canadian fisheries were estimated by expanding the harvest rates for Area 3 or Area 3&4 fisheries respectively using the following equation:

$$HR_{a,y}^{Cdn} = \widehat{HR}_{a,y} \cdot HR_a^{ratio} \quad \text{for } a \in \{3,4\};\ y \in\ Y^{ORR} \tag{8}$$

where $\widehat{HR}_{a,y}$ is the area-specific harvest rate and HR_a^{ratio} represents an area-specific conversion ratio used for converting area harvest rate into the harvest rate for all Canadian fisheries (Area 1-5).

The conversion ratio was determined as the average ratio between Canadian and area-specific harvest rates from the 1982-1995 run reconstruction, that is,

$$HR_a^{ratio} = \sum_{y=1982}^{1995} \left(\frac{HR_{a,y}^{Cdn}}{HR_{a,y}} \right) \Big/ 14 \quad \text{for } a \in \{3,4\} \tag{9}$$

where $HR_{a,y}$ represents the area- and year-specific Pink harvest rates from the run reconstruction analysis and $HR_{a,y}^{Cdn}$ represent the corresponding Canadian harvest rates also from the run reconstruction analysis.

Standardized Canadian Commercial Effort

Pink salmon are harvested using commercial purse seine and gillnet gear types in Area 3 and 4. Purse seine gear is the primary method used to capture Pink salmon. Since Pink salmon are also caught, largely as a bycatch in Sockeye fisheries, we converted gillnet effort into seine equivalents to derive a single measure of fishing effort for these fisheries. The seine equivalents represented by gillnet effort was then added to the seining effort to determine the total adjusted effort. Explicitly, area- and year-specific total adjusted effort ($E_{a,y}^{adj}$) was determined as,

$$E_{a,y}^{adj} = E_{a,y}^{seine} + \left(SE_{a,y}^{ratio} \cdot E_{a,y}^{gillnet} \right) \quad \text{for } a \in \{3,4\}; y \in Y^{ORR} \tag{10}$$

where $E_{a,y}^{seine}$ and $E_{a,y}^{gillnet}$ represents area- and year-specific seine and gillnet commercial fishing effort and $SE_{a,y}^{ratio}$ represents the area- and year-specific seine equivalency ratio used to convert the gillnet effort into a seining equivalent measure of effort. Area- and year-specific effort was derived from the BC Hail database. Years prior to 1982 were values were provided by Dave Peacock, and for 1982 onwards weekly effort and catch values were derived from the publically available BC Hail database, only Alaskan Weeks 29-36 were retained because these are the weeks that overlap with the return timing of Canadian Pink and Chum salmon.

The area- and year-specific seine equivalency ratio was also determined from the historical and current BC Hail data set. For areas and years where data was available, the area- and year-specific seine equivalency ratio was directly estimated from BC commercial gillnet and seine fisheries data (i.e., BC Hail database) as,

$$SE_{a,y}^{Ratio} = \frac{CPUE_{a,y}^{gillnet}}{CPUE_{a,y}^{seine}} \quad \text{for } a \in \{3,4\}; y \in Y^{ORR} \tag{11}$$

where $CPUE_{a,y}^{gillnet}$ and $CPUE_{a,y}^{seine}$ representing the area-specific yearly Pink catch per unit effort for the commercial gillnet and seine fisheries respectively. For instances where area- and year-specific seine equivalency ratios could not be determined (i.e., 1954-1981 due to missing harvest data), values were infilled with an average area-specific ratio ($\overline{SE}_a^{Ratio}$) computed from available years, that is,

$$\overline{SE}_a^{Ratio} = \sum_{y=1}^{Y} SE_{a,y}^{Ratio} / Y \tag{12}$$

where Y represents the total number of years where $SE_{a,y}^{Ratio}$ is available from 1982-2014.

Area 4 Catch and Effort

Given the large relative magnitude of Area 3 purse seine fisheries, interception of Area 4 Pink Salmon stocks in Area 3 fisheries is more important than the interception of Area 3 Pink Salmon stocks in Area 4 fisheries. As such, Area 4 catch and effort values in the preceding calculations were the summation of Area 3 and Area 4 catch and effort values.

Alaskan Harvest Rates

For years prior to the to the run reconstruction analysis (i.e., 1954-1981) the Alaskan harvest rate was set to the average of the run reconstruction analysis (18.5%), that is,

$$\overline{HR}_a^{Ak} = \sum_{y_2=1982}^{1995} HR_{a,y_2}^{Ak} \Big/ 14 \quad \text{for } a \in \{3,4\}; 1982 \leq y \leq 1995 \tag{13}$$

where HR_{a,y_2}^{Ak} were Alaskan harvest rates determined in the 1982-1995 reconstruction analysis (Gazey and English 2000).

For years after the run reconstruction analysis (i.e., 1996-2017), area- and year-specific Alaskan harvest rates were predicted directly from the harvest rate relationship curve (i.e., Equation 7), where yearly effort represented the Alaskan purse seine fishery in District 101, 102 and 104 over Alaskan weeks 28-35. Alaskan weeks range was shifted by one week relative to Canadian Commercial fishery to accommodate for travel times between the Alaskan and Canadian commercial fishing areas.

Assumptions

The assumptions associated with the various models used to compute the exploitation rates for Area 3, 4 and 5 Pink and Chum salmon stocks are listed below. These are the same assumptions as those previously described for these models (English et al. 2016, Appendix E):

Pink Salmon Run Reconstruction Model

O. **Assumption 12 – HRs for Area 3 Inside and Area 4 Pink salmon stocks 1982-95:** The combination of daily catch estimates, migration route, run timing and annual escapement estimates for Northern Boundary Pink salmon stocks in the Gazey and English (2000) run reconstruction model produced reliable estimates of the HRs for Area 3 Inside and Area 4 Pink salmon stocks in Area 3 and Area 4 fisheries and ERs in Alaskan fisheries.

P. **Assumption 13 – Equal vulnerability:** The vulnerability of each Pink salmon stock in each Northern Boundary fishery will be proportional to the abundance of that stock in that fishery during each fishing period.

Effort–Harvest Rate (EHR) Analysis Models

Q. **Assumption 14 – Area 3 HRs for Area 3 Inside Pink salmon:** The EHR relationship derived for Area 3 Inside Pink salmon stocks harvested in Area 3 fisheries for 1982-95 can be used to estimate annual HRs for 1954-81 and 1996-2014 using weekly fishing effort estimates and Pink salmon CPE estimates for Area 3 seine and gillnet fisheries in these years.

R. **Assumption 15 –Area 3 and 4 HRs for Area 4 Pink salmon:** The EHR relationship derived for Area 4 Pink salmon stocks in harvested Area 3 and 4 fisheries for 1982-95 can be used to estimate annual HRs for 1954-81 and 1996-2014 using weekly fishing effort estimates and Pink salmon CPE estimates for Area 3 and 4 seine and gillnet fisheries in these years.

S. **Assumption 16 –Area 3 and 4 HRs for Area 5 Pink salmon:** Only half (50%) of Area 5 Pink salmon are vulnerable to fisheries in Area 3 and 4; and the run-timing of Area 5 Pink salmon is one week later than that for Area 4 Pink salmon. The Effort–HR relationship for Area 4 Pink salmon stocks is appropriate for estimating HRs for Area 5 Pink salmon stocks.

T. **Assumption 17 – Alaska ERs for Area 3 Inside and Area 4 Pink salmon:** EHR relationships for Area 3 Inside and Area 4 Pink salmon stocks harvested in Alaska seine fisheries in Districts 101-104 for 1982-95 can be used to estimate annual ERs 1996-2014 from annual fishing effort estimates for these Alaskan fisheries from 1996-2014. The average Alaska ERs for 1982-95 provide a reasonable estimate of the annual Alaska ERs for Area 3 and Area 4 Pink salmon from 1954-81.

U. **Assumption 18 – Alaska ERs for Area 5 Pink salmon:** ERs for Area 5 Pink salmon in Alaskan fisheries is the same as that estimated for Area 4 Pink salmon.

V. **Assumption 19 – Canadian ERs for Area 3 Inside, Area 4 and Area 5 Pink salmon:** The average portion that Area 3 and Area 4 HRs were of the total Canadian HRs during the 1982-95 period is appropriate for the 1954-81 and 1996-2014 to expand the Area 3 and 4 HRs to total Canadian HRs that can be combined with Alaskan ERs to compute total Canadian ERs for Area 3 Inside, Area 4 and Area 5 Pink salmon stocks.

Chum Models

W. **Assumption 20 – Canadian HRs for Area 3 Chum stocks for 1982-14:** Area 3 Chum migrating through fisheries in Area 3, 4 and 5 have the same weekly HR as those estimated for co-migrating Nass (Area 3) sockeye using the NBSRR model results for 1982-14;

X. **Assumption 21 – Canadian HRs for Area 4 Chum stocks for 1982-14:** Area 4 Chum migrating through fisheries in Area 3, 4 and 5 have the same weekly HRs as those estimated for co-migrating Skeena (Area 4) sockeye using the NBSRR model results for 1982-14;

Y. **Assumption 22 – Canadian HRs for Area 5 Chum stocks for 1982-14:** Area 5 Chum migrating through fisheries in Area 3, 4 and 5 have the same weekly HRs as those estimated for co-migrating Skeena (Area 4) sockeye using the NBSRR model results for 1982-14.

Z. **Assumption 23 – Run timing for Area 3-5 Chum salmon:** The 1994-2009 daily Nass fishwheel Chum catch per unit effort provides a reasonable estimate of the run timing for all Area 3 Chum stocks; the Skeena test fishery provides a reasonable estimate of the run timing for all Area 4 Chum stocks; and the run timing for Area 5 Chum was estimated to be one week later than that for Area 4 Chum.

AA. **Assumption 24 – Non-retention fisheries:** The mortality rate for Chum salmon released during non-retention fisheries was assumed to be 10% for purse seine fisheries and 60% for gillnet fisheries. Therefore, weekly HRs estimated for sockeye salmon were reduced by these factors during weeks when Chum non-retention regulations were in effect.

BB. **Assumption 25 – Alaska ERs for Area 3 Chum salmon**: Area 3 Chum migrating through Alaskan fisheries have the same annual ER as those estimated for Nass (Area 3) Pink salmon from the Area 3 EHR Model for all years.

CC. **Assumption 26 – Alaska ERs for Area 4-5 Chum salmon:** Area 4 and 5 Chum migrating through Alaskan fisheries have the same annual ER as those estimated for Skeena (Area 4) Pink salmon from the Area 3+4 EHR Model for all years.

DD. **Assumption 26a – Canadian HRs for Area 3, 4 and 5 Chum stocks from 1954-81:** Canadian HRs for Area 3, 4 and 5 Chum stock from 1954-81 were assumed to be equal to those estimated for Pink salmon for these years using the A3-EHR Model and A3+4 EHR Model.

MODEL IMPLEMENTATION

The Pink & Chum Model is run by calling the `PinkChumModel()` function in the NCCSDB R package (Appendix C). The routine expects an active connection to the NCC Salmon Database and a file path to the Chum Model Excel file. Calling the function executes the following sequential steps:

1. import run Gazey and English (2000) Pink salmon reconstruction harvest rates from the NCC Salmon Database;
2. import historical BC Hail data from the NCC Salmon Database;
3. import current BC effort and Pink catch data (i.e., BC Hail) data from the NCC Salmon Database (originally imported from the Sockeye Northern Boundary Run Reconstruction);
4. import current Alaskan effort and Pink catch data from the NCC Salmon Database (originally imported from the Sockeye Northern Boundary Run Reconstruction);
5. import Chum harvest rate data from the Chum Model Excel file;
6. compute standardized total effort (seine equivalence boat days);
7. estimate Pink harvest rates for years outside the run reconstruction (i.e., 1954-1981 and 1996-2017) for Area 3 and Area 4;
8. compute Pink and Chum exploitation rates;
9. update NCC Salmon Database with Pink and Chum exploitation rate estimates; and
10. optionally, output diagnosis and exploitation rates to an Excel file if specified.

Model Structure

The all calculations are conducted within the `PinkChumModel()` function with helper functions used to determine Excel column counts (`ExcelColNum`), as well as create Excel worksheets (`BlankWorkSheet`) and write out diagnostic results (`PinkChumDiagnostics`). These functions are included in the **NCCSDB** R package.

RESULTS

Effort to Pink harvest rate curves were generated based on the 1982-1995 run reconstruction analysis (Figure 1). Alaskan harvest rates were generally lower that area wide harvest rates, with a lower theoretical maximum harvest rate. The 95% confidence regions indicated a generally precise fit for most effort values except in some instances at the lower end of the effort scale. Three out of the four curves showed a noticeable expansion in the confidence region the lower effort level. This can be attributed to removing or including few available observations at lower effort values and is a known limitation of conducting a bootstrap on a small data set (Efron and Tibshirani 1986). Because the confidence regions are not directly used in the current Pink and Chum model implementation this does not affect current exploitation rate estimates. However, it should be noted that fishing effort levels have been substantially lower in recent years than during the 1982-1995 years used to define the effort-harvest rate relationship. For example: 50-289 boat-days is the range on seine equivalent effort since 2007 for Area 3 compared to 575-3013 boat-days in the 1982-1995 period. Since it is reasonable to assume that these effort-harvest rate curves must go through the origin (i.e. the harvest rate is zero when there is no fishing effort), the harvest rate estimates are very low for recent years but the uncertainty associated with these harvest rates is high for three of the four fisheries where these effort-harvest rate relationships are used to derive harvest rates.

Point estimates for each effort to harvest rate curve (Table 1) used to predict Pink salmon harvest rates in Area 3 and Area 4 for years outside the run reconstruction years (Figure 2). Harvest rate estimates were then used to estimate Canadian and Total exploitation rates for Pink and Chum salmon in Area 3, Area 4, and Area 5 (Figure 3).

DISCUSSION

The conversion of the Pink & Chum Model from an Excel macro to an R routine provides a number of advantages. Recently, the data import, processing and output steps associated with maintaining and updating NCC Salmon Database have been converted to R routines. By converting the Pink & Chum model to R, it is possible to re-run and update the Pink & Chum Model component of the NCC Salmon Database as part of a master update script. This will help speed and streamline the process of updating the NCC Salmon Database with revised data, and could be an important component for conducting future sensitivity analyses on NCC Salmon Database output. Impacts of analysis assumptions on final management designations and decisions can be investigated by modifying input data and model assumptions then comparing key output metrics. The conversion of the Pink & Chum model to an R routine makes these analyses more manageable by making it fully scriptable within the R computing environment, which also fits in with the recent initiative of converting all major NCC Salmon Database computations to R routines.

While the model can be run without within a larger update scripts without any general intervention, the model still retains the ability to save diagnostics and output to an Excel workbook (see Appendix C). These diagnostics should be output and reviewed any time the NCC Salmon Database is updated to ensure the model executed correctly and that input data was correct.

A comparison of the Excel macro results with the R routine, which should produce the same results except for Area 4 exploitation rate estimates prior to 1982, revealed a small error in the Excel macro. The 1994 Area 4 gillnet effort is currently missing from the BC Hail database, and while this effort data is manually added back into effort calculations in the Pink & Chum Model, this correction was missing from the average seine equivalence ratio calculation (see Equations 11 and 12). As this average equivalency ratio is used for converting gillnet to seine equivalences for years prior to 1982, the Area 4 seine equivalent effort values were affected, which in turn affected the exploitation rate estimates by a small amount. This error can be recreated by running the R routine under “legacy” mode (see Appendix C).

By default, the average seine equivalence ratio (see Equations 11 and 12) were restricted to only use data from 1982-2014, so that expanding the timeline will not affect historical estimates compared to previous analyses. This restriction can however be changed to use any subset of years after 1982, including the full timeline (see Appendix C).

Finally, the most critical assumption of this analysis is that the distribution and efficiency of fishers that harvest Pink salmon in Areas 1-5 outside the Pink run reconstruction years (i.e., 1954-1981 and 1996-

2017) is like the behaviour during the run reconstruction years (i.e., 1982-1995). This assumption is more reasonable for the pre-1982 period that the post-1995 period. For example, no net fisheries have been permitted in Area 1 after 1997. However, Area 1 Pink salmon catches represented only 0.6% and 1.8% of the total Canadian catch of Area 3 and Area 4 Pink salmon, respectively.

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Table 1. Parameter estimates for area-specific harvest rate to effort relationships determined from the 1982-1995 Pink salmon run reconstruction analysis.

		HR_{max}				$E_{0.5HR_{max}}$			
Scope	**Area**	**Estimate**	**SE**	**Lower**	**Upper**	**Estimate**	**SE**	**Lower**	**Upper**
Area Wide	Area 3	1.43	0.44	0.88	4.37	3,599	1,676	1,505	15,127
	Area 4	0.79	0.27	0.48	6.42	2,004	1,560	395	36,351
Alaskan	Area 3	0.31	0.14	0.18	-	2,022	2,432	440	-
	Area 4	0.37	0.21	0.20	-	3,066	3,628	421	-

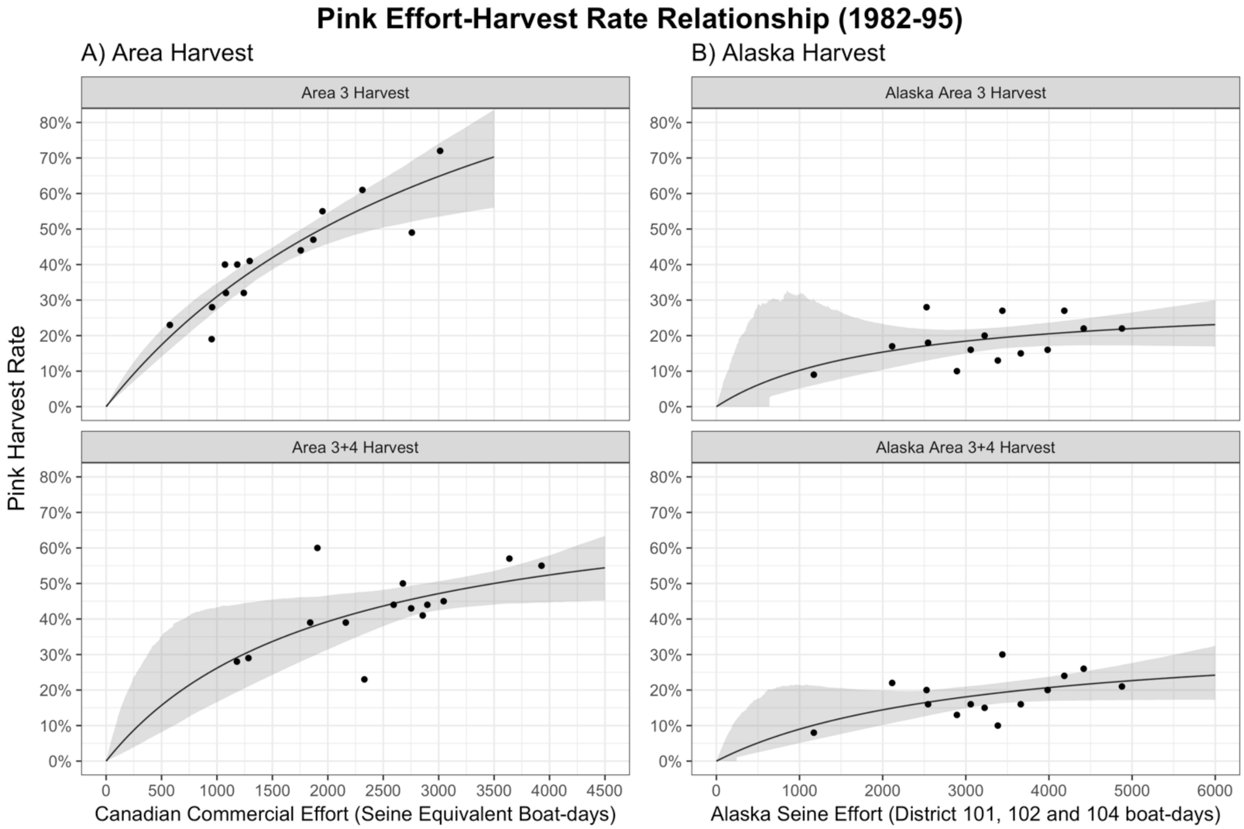


Figure 1. Estimated area-specific harvest rate to effort relationships for A) total area harvest and B) Alaskan harvest. Grey shading indicates 95% confidence region for the curve.

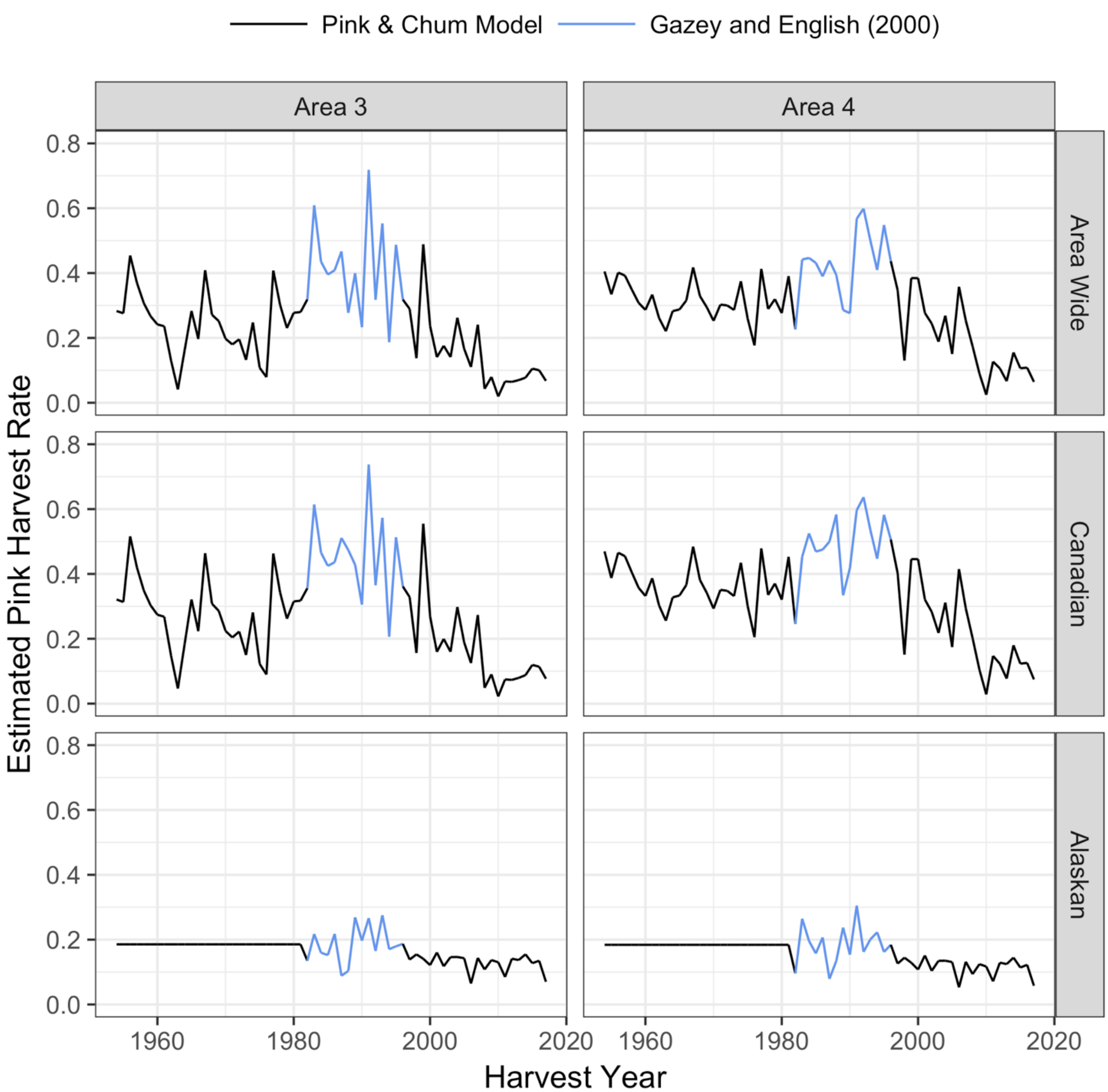


Figure 2. Estimated Pink salmon harvest rates (Area Wide, Canadian, and Alaskan) for Area 4 and Area 5. Values derived from the Pink&Chum Model are indicated in black, while Gazey and English (2000) estimates are indicated with blue.

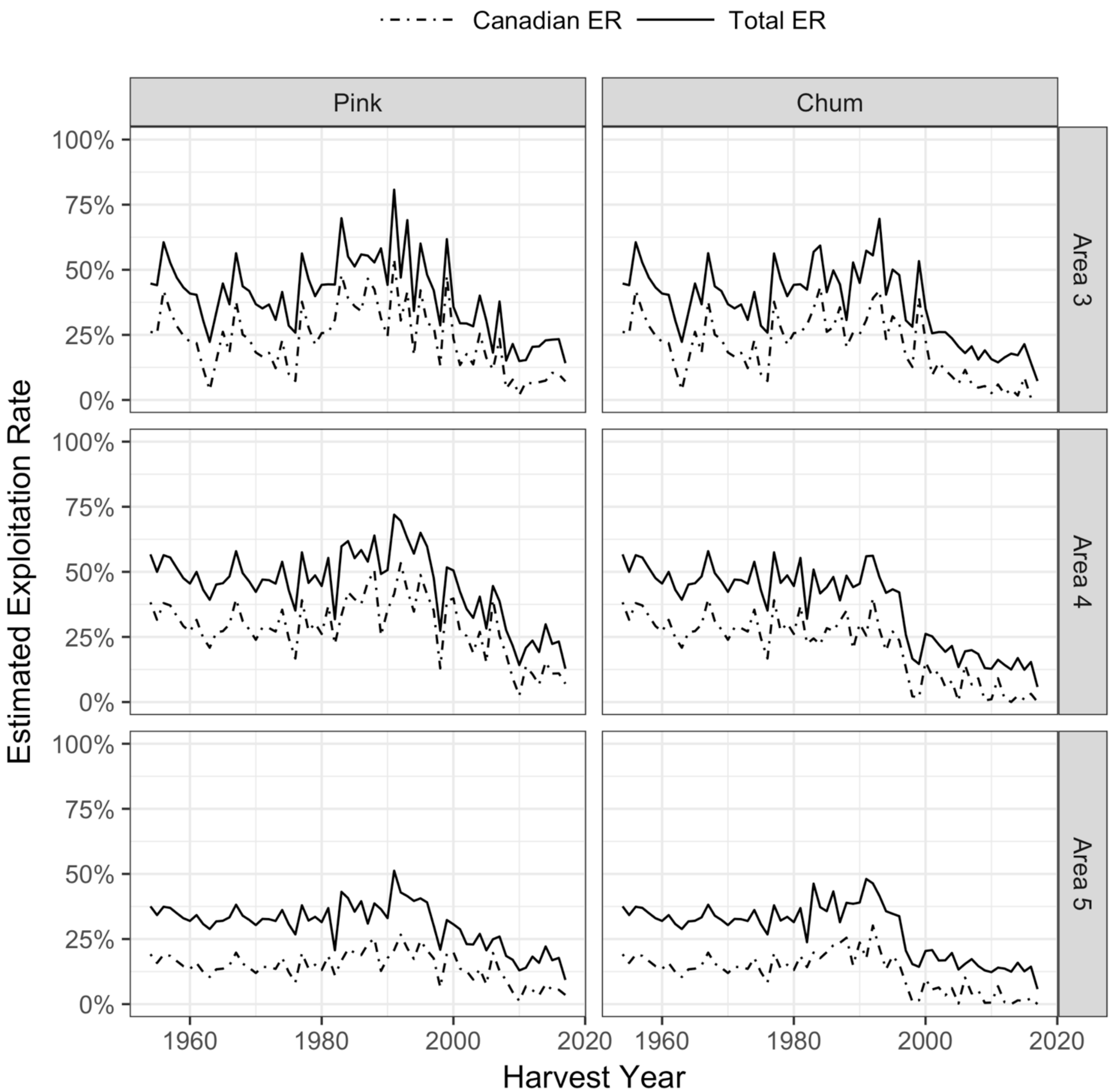
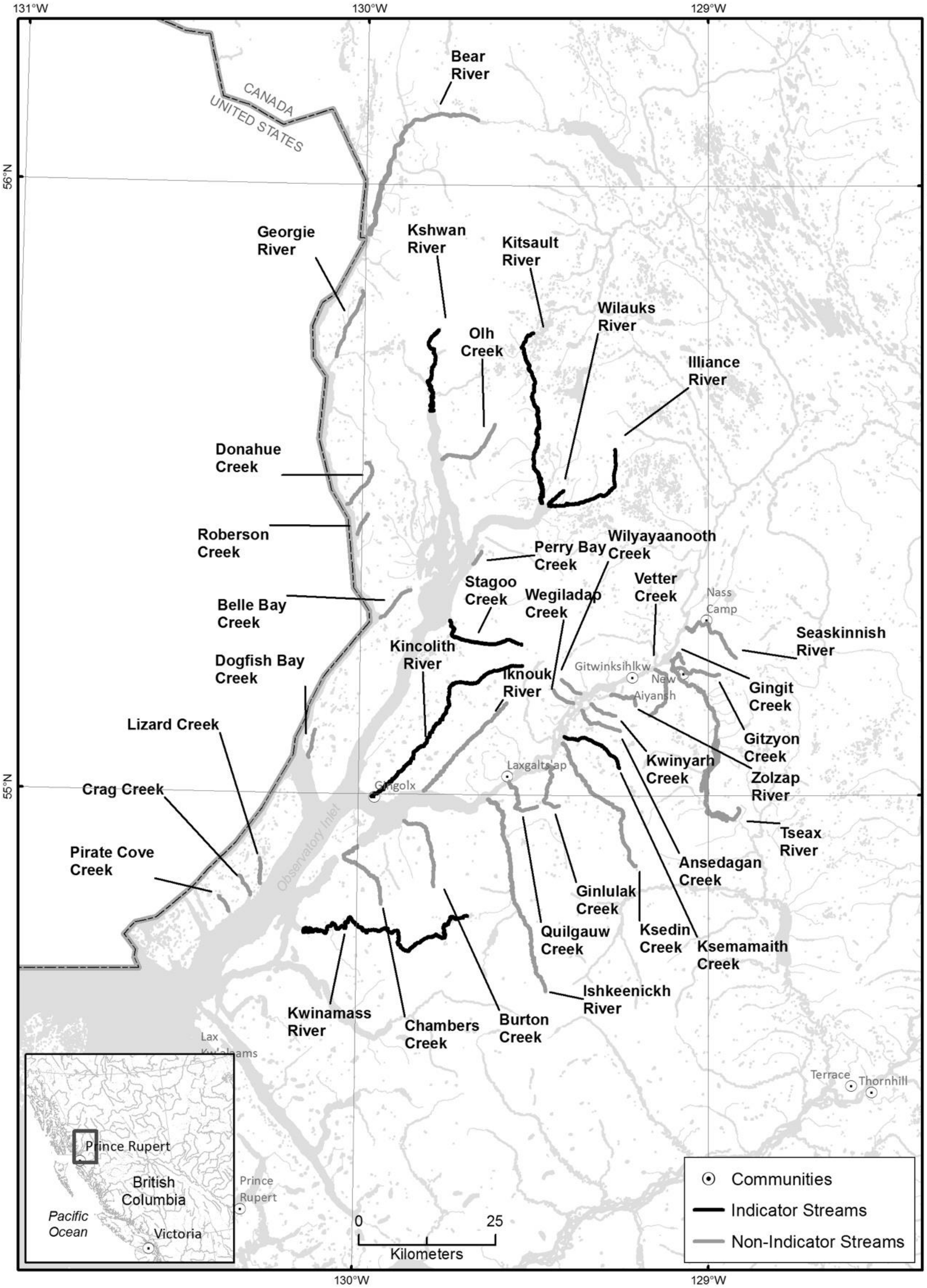


Figure 3. Estimated Pink and Chum Canadian and Total exploitation rates for Area 3, Area 4 and Area 5.

APPENDIX A

Location of Pink and Chum Salmon Indicator Streams in Area 3



APPENDIX B

Pink Salmon Run Reconstruction Results (1982-1995)

Table B1. Area 3 Pink salmon run reconstruction results included in the Pink & Chum model (from Gazey and English 2000).

	Effort (Boat Days)		Harvest Rates			Exploitation Rates	
Year	**BC**	**Alaskan**	**Area Wide**	**Canadian**	**Alaskan**	**Canadian**	**Total**
1982	1,242	3,385	0.319	0.356	0.135	0.308	0.443
1983	2,312	4,418	0.609	0.614	0.217	0.481	0.698
1984	1,756	3,984	0.435	0.466	0.160	0.391	0.551
1985	1,183	3,661	0.395	0.425	0.152	0.360	0.513
1986	1,295	4,878	0.409	0.436	0.218	0.341	0.559
1987	1,869	1,172	0.467	0.511	0.089	0.466	0.554
1988	956	2,893	0.277	0.474	0.103	0.425	0.528
1989	1,072	4,185	0.399	0.428	0.269	0.313	0.582
1990	575	3,226	0.233	0.305	0.197	0.245	0.442
1991	3,013	3,440	0.718	0.737	0.266	0.541	0.807
1992	1,081	3,059	0.318	0.365	0.165	0.305	0.470
1993	1,952	2,528	0.553	0.573	0.275	0.415	0.691
1994	952	2,114	0.187	0.206	0.171	0.171	0.342
1995	2,758	2,546	0.487	0.513	0.179	0.421	0.601

Table B2. Area 4 Pink salmon run reconstruction results included in the Pink & Chum model (from Gazey and English 2000).

	Effort (Boat Days)		**Harvest Rates**			**Exploitation Rates**	
Year	**BC**	**Alaskan**	**Area Wide**	**Canadian**	**Alaskan**	**Canadian**	**Total**
1982	2,330	3,385	0.226	0.246	0.096	0.376	0.472
1983	2,594	4,418	0.442	0.453	0.265	0.511	0.776
1984	3,045	3,984	0.447	0.525	0.196	0.593	0.789
1985	2,752	3,661	0.431	0.469	0.157	0.588	0.746
1986	1,841	4,878	0.390	0.475	0.207	0.539	0.746
1987	2,898	1,172	0.439	0.500	0.079	0.663	0.742
1988	2,162	2,893	0.394	0.583	0.134	0.647	0.782
1989	1,284	4,185	0.286	0.334	0.237	0.400	0.637
1990	1,180	3,226	0.276	0.417	0.154	0.490	0.643
1991	3,638	3,440	0.567	0.597	0.305	0.574	0.879
1992	1,906	3,059	0.599	0.637	0.162	0.716	0.878
1993	2,677	2,528	0.500	0.536	0.201	0.614	0.815
1994	2,856	2,114	0.409	0.447	0.223	0.523	0.746
1995	3,928	2,546	0.548	0.582	0.162	0.680	0.842

APPENDIX C

Pink & Chum Model R Code

The Pink & Chum Model is run by calling the `PinkChumModel()` function in the NCCSDB package. The default behavior will be to update the `[INPUT Pink ERs]` and `[INPUT Chum ERs]` tables in the NCC Salmon Database. Optionally, diagnostics and exploitation rates can be exported to an Excel file if the `xlsx.out` argument is specified.

Arguments

`channel`	an active RODBC connection to the NCC Salmon Database.
`xlsx.Chum`	character string indicating the file path to the Chum Model Excel file.
`start.yr`	integer indicating first year (with century) of available data, default value is 1954.
`end.yr`	integer indicating last year (with century) of analysis, should be less than available data.
`seine.eq.yrs`	integers indicating years (with century) over which the average seine equivalency factor for converting BC gillnet effort into BC Seine equivalents should be computed. Default is 1982-2014.
`db.update`	logical indicating whether the NCC Salmon Database should be updated. If `TRUE` the `[INPUT Pink ERs]` and `[INPUT Chum ERs]` tables will be updated.
`xlsx.out`	optional - character string indicating file path to an output Excel output. If the Excel file already exists the following four worksheets will be created or updated: • *Area 3 Pink ERs* –Nass Pink ER diagnostics • *Area 3+4 Pink ERs* –Skeena Pink ER diagnostics • *Pink ERs for TRTC* – Final Pink ER values • *Chum ERs for TRTC* –Final Chum ER values The latter contain the values inserted into the `[INPUT Pink ERs]` and `[INPUT Chum ERs]` NCC Salmon Database tables if `db.update = TRUE`.

```
PinkChumModel <- function(channel, xlsx.Chum, start.yr, end.yr, db.update=TRUE, xlsx.out=NULL, legacy=FALSE)
 {
  # Load dependencies -----------------------------------------------------
  if (!require(openxlsx)) stop("The 'openxlsx' package is required.")
  if (!require(plyr)) stop("The 'plyr' package is required.")
  if (!require(reshape2)) stop("The 'reshape2' package is required.")
  if (!require(stringr)) stop("The 'stringr' package is required.")

  # Default Settings ------------------------------------------------------
  start.yr.hail <-  1982 # first year of the Hail data

  # Constants and Derived Parameters --------------------------------------
  n.yrs <- end.yr - start.yr + 1          # Number of assessment years
  areas <- paste("Area", seq(3, n.area))  # Area Names
  gear.types <- c('gillnet', 'seine')   # Gear types of interest
  weeks.ak <- as.character(seq(24,37))  # Alaska Weeks
  adj.week <- weeks.ak[6:13]  # Week 29-36 taken from marco indexing - yes none of this is straight forward

  # Variable Initialization -----------------------------------------------
  # Harvest Rates
  Hr <- HrCDN <- HrAk <-  matrix(
    data = NA,
    nrow = n.area - 2,
    ncol = length(start.yr:end.yr),
    dimnames = list(
      paste('Area', seq(3,n.area)),
      as.character(start.yr:end.yr)
    )
  )

  # Canadian Catch and Effort Arrays:  Area x Gear x Week X Year
  catch <- effort <- array(
    data = 0,
    dim = c(length(areas) - 2, length(gear.types), length(weeks.ak), n.yrs),
    dimnames = list(
      areas,                            # Dimension 1: Area
      gear.types,                       # Dimension 2:  Fishing Gear
      as.character(weeks.ak),           # Dimension 3:  Alaska Week
      as.character(seq(start.yr, end.yr)) # Dimension 4:  Year
    )
  )

  # Total Effort Vector: total effort by year
  # @Verify missing effort values are assumed to be zero
  effortAK <- structure(.Data = rep(0, n.yrs), dim = n.yrs,dimnames = list(as.character(start.yr:end.yr)))

  avgHrRatio <- avgHrAk <- structure(
    .Data = rep(NA,3),
    dim = c(n.area-2),
    dimnames = list(paste("Area", 3:n.area))
  )

  # Average run timing diagnostic, Area 3 and 4 only
  timing <- structure(
    .Data = rep(NA, 2* length(weeks.ak)),
    .Dim = c(2, length(weeks.ak)),
    .Dimnames = list(paste("Area", 3:4), as.character(weeks.ak))
  )

  # Seine Equivalents
  seine.eq <- structure(
    .Data = rep(NA, 2* n.yrs),
    .Dim = c(2, n.yrs),
    .Dimnames = list(paste("Area", 3:4), as.character(start.yr:end.yr))
  )

  # Run Reconstruction Estimates (1982-1995) ----------------------------
  # Retrieve and save the Gazey and English 2000 Pink Run reconstruction
  # harvest rate estimates from the NCC Salmon Database.

  rr <-  sqlFetch(channel, "DATA Pink_RR")
```

```
yrs <- as.character(1982:1995)
areas <- c(
'Area 3' = "Area 3",   # Area 3 (Nass)
'Area 4' = 'Area 3+4'  # Area 4 (Skeena)
)

for (a in seq_along(areas)) {
      area <- names(areas)[a]
  # Retrieve harevest rates from run reconstruction
  x <- subset(rr, StatArea == areas[a] & Year %in% yrs)
  Hr[area, yrs]    <- as.numeric(x$`Area HR`)        # Total area harvest rate
  HrCDN[area, yrs] <- as.numeric(x$`Canadian HR`)    # Canadian harvest rate
  HrAk[area, yrs]  <- as.numeric(x$`Alaska HR`)      # Alaskan
  avgHrRatio[area] <- mean(HrCDN[area, yrs]/Hr[area, yrs]) # mean Canadian HR to total HR ratio used to
convert predicted area harvest to canadian harvest
  avgHrAk[area]  <- mean(HrAk[area, yrs])    # Avg Alaskan harvest
}


# Historical BC Hail ----------------------------------------------------
# Current BC hail data only goes back to 1982.  To extend the time line
# to 1954, historical BC Hail data was obtained from Dave Peacock.
# Historical data will be imported first, followed by the current BC Hail.

if (start.yr > 1981) stop("Analysis start year must be prior to 1981")

hist.bc.hail <- sqlFetch(channel, "DATA Hist_BC_HAIL")
index <- as.matrix(hist.bc.hail[c('StatArea', 'Gear','AKWeek', 'Year')])
effort[index] <- hist.bc.hail$BoatDays


# Current BC_HAIL (1982-present) -------------------------------------------

dat <- sqlFetch(channel, "DATA NBRR_BC_HAIL")
dat <- subset(dat, YEAR >= start.yr.hail & YEAR <= end.yr)
if (is.numeric(dat$GEAR)) dat$GEAR <- formatC(dat$GEAR, width = 2, flag="0")


#--- Effort and Catch Summaries ---
hail.piv <- rbind(
  #--- AREA 3 ---
  ddply(
    .data =  subset(dat,  AK_WEEK  %in% adj.week & GEAR %in% c("01", "02") & AREA %in% 3),
    .variables = c("GEAR", "YEAR", "AK_WEEK"),
    .fun = summarise,
    Area = "Area 3",
    Effort = sum(BOATS, na.rm=T),
    Catch = sum(PINK, na.rm=T)
  ),
  #--- AREA 3+4 ---
  # Note that Area 4 includes all of area 3 effort
  ddply(
    .data = subset(dat,  AK_WEEK  %in% adj.week & GEAR %in% c("01", "02") & AREA %in% 3:4),
    .variables = c("GEAR", "YEAR", "AK_WEEK"),
    .fun = summarise,
    Area = "Area 4",
    Effort = sum(BOATS, na.rm=T),
    Catch = sum(PINK, na.rm=T)
  )
)
if (nrow(hail.piv) == 0) stop("BC_HAIL pivot failure")

# 1994 Gillnet Workaround:
# BC Hail database is missing effort data for Area 4 gillnet effort in 1994.
# The actual Area 4 gillnet effort values were loaded from the excel
# workbook when loading the 1954 (start.yr) to 1991 values.
# NOTE > adding missing area 4 effort directly to the BC Hail Pivot data
# ends up affect the Seine EQ calculations so that they do not match the
# original output from the Excel Macro. Enabling legacy mode recreates the
# macro bug (see issue #2)
#
```

```
  # The "Timing" metric (a diagnostic) in the original Excel Macro (does correctly
  # include this effort, but the Seine EQ calculations in the original macro does not
  # As such, we will keep 2 versions of the BC Hail weekly catch/effort summary
  # pivot table:
  #  - hail.piv  missing 1994 gillnet effort for Area 4
  #  - hail.piv2 correct effort data

  # Determine which records in long format (1994 gillnet Area 4 for weeks of interest)
  rec <- rownames(subset(hail.piv, YEAR == 1994 & Area == "Area 4" & GEAR == '01'))
  wks <- as.character(hail.piv[rec,'AK_WEEK'])
  hail.piv2 <- hail.piv
  hail.piv2[rec,'Effort'] <- hail.piv[rec,'Effort'] + effort['Area 4', 'gillnet', wks, '1994']

  # Update effort and catch arrays for recent BC Hail data for AK_Weeks of interest
  # Note: gillnet (g=1) and seine (g=2)).
  for (area in paste('Area', 3:4)) {
    for (g in 1:2) {

      #-- Save effort --  Use  effort corection (hail.piv2)
      x <- dcast(subset(hail.piv2, Area == area & GEAR == paste0('0',g)), AK_WEEK ~ YEAR,
value.var="Effort")  # long to wide conversion
      x[is.na(x)] <- 0   # set missing effort values to zeros (see #652)
      yrs <- colnames(x)[-1]
      effort[area, gear.types[g], as.character(x$AK_WEEK), yrs] <-  as.matrix(x[ ,yrs]);  rm(x)

      # -- Save catch --
      x <- dcast(subset(hail.piv, Area == area & GEAR == paste0('0',g)), AK_WEEK ~ YEAR,
value.var="Catch")  # long to wide conversion
      x[is.na(x)] <- 0   # set missing effort values to zeros (see #652)
      yrs <- colnames(x)[-1]
      catch[area, gear.types[g], as.character(x$AK_WEEK),yrs] <- as.matrix(x[ ,yrs]);  rm(x)
    }
  }


  # Alaskan Effort (1982-present) -----------------------------------
  # Note the fishery occurs earlier so we shift the adjustment week interval
  # earlier by one week.
  dat <- sqlFetch(channel, "DATA NBRR_PRO_AK")
  dat <- subset(dat, Year >=1982 & Year <= end.yr)
  if (is.numeric(dat$Gear)) dat$Gear <- formatC(dat$Gear, width = 2, flag="0")

  # Read in PRO_AK data only keeping Seine for AKwk 28-35 and FisheryNO 20, 12, 26, 27
  dat <- subset(
    x = dat,
    subset = Gear == formatC(which(gear.types == gear), width = 2, flag = 0) &
      AKwk  %in% as.character(as.numeric(adj.week) - 1) &    # Shifted adjustment week see issue #3
      FisheryNo %in% c(20, 21, 26, 27)
  )
  # Add boat days calculation if it does not already exist (different version of the NBRR output
  # may be missing this field)
  if (("Boat-days" %in% colnames(dat)) == FALSE) {
    dat[['Boat-days']] <- as.numeric(dat$Boats) * as.numeric(dat$OpenDays)
  }

  # Create a pivot table of total Seine effort (boat days) by year
  eff.piv <- ddply(dat, c("Year"), summarise,
        N    = sum(!is.na(`Boat-days`)),
        Total = sum(`Boat-days`, na.rm=T)
  )
  if(nrow(eff.piv) == 0) stop("Alaska seine effort calculation error")

  # Check that avialable data matches specified analysis years
  if (!all(eff.piv$Year %in% names(effortAK)))
    warning("Available Alaska Effort Years does not match analysis years.")

  # Update total Alaska yearly effort for 1982-present.
  effortAK[intersect(names(effortAK), as.character(eff.piv$Year))] <- eff.piv$Total

  # Timing calculation ----------------------------------------------------
  # Diagnostic metric used to determine the propoportion of catch per unit
```

```
# effort by week relative to total catch per effort for the year, averaged
# over years. Allows a quick assessment of fishing effort over the season.

# Average Weekly CPUE (averaged over Years)
cpe.avg <- ddply(
  .data = hail.piv2,
  .variables = c("Area", "GEAR", "AK_WEEK"),
  .fun = summarise,
  Effort.Total = sum(Effort, na.rm=T),
  Catch.Total = sum(Catch, na.rm=T),
  avgCPE = Catch.Total/Effort.Total
)
# recast as a 3d array (area x gear x week)
avgCPE <- acast(cpe.avg, formula = Area ~  GEAR ~ AK_WEEK , value.var = "avgCPE")

cpe.tot <-  ddply(
  .data = cpe.avg,
  .variables = c("Area", "GEAR"),
  .fun = summarise,
  sumCPE = sum(avgCPE)
)
# Recast as matrix
sumCPE <- acast(cpe.tot, formula = Area ~  GEAR , value.var = "sumCPE")

 # Note a subset of Alaska weeks are used.
 for (area in paste("Area", 3:4)) {
   for (week in adj.week) {
     timing[area, week] <-  mean(avgCPE[area, , week] / sumCPE[area, ])
   }
 }


# Seine Equivalents (1982-present) ----------------------------------------
# Calculate seine equivalents (SE) by year and average SE's for 1982-present
# To reproduce the values produced by the original Excel Marco we use the
# version of the BC Hail weekly summary (hail.piv) that is missing the
# 1994 Area 4 Gillnet effort (see issue #2)

# Uses hail.piv2 (with 1994 correction) under non-legacy mode

#Summarise total catch and effort by year
catcheff.yr <- ddply(
  .data = if (legacy) hail.piv else hail.piv2,
  .variables = c("Area", "GEAR", "YEAR"),
  .fun = summarise,
  Effort = sum(Effort, na.rm=TRUE),
  Catch = sum(Catch, na.rm=TRUE)
)

# Catch per Effort for each area, gear type and year
sum.catch <- acast(catcheff.yr, formula = Area ~  GEAR ~ YEAR , value.var = "Catch")
sum.effort <- acast(catcheff.yr, formula = Area ~  GEAR ~ YEAR , value.var = "Effort")

cpe <- sum.catch / sum.effort

# Check that no undefined results (i.e., dividing by zero)
if (any(check <- is.infinite(cpe))) cpe[check] <- NA

# Seine Equivalents = Gillnet / Seine Catch Per Effort
seine.eq.avail <- cpe[ ,'01', ] / cpe[ ,'02', ]
avg.seine.eq <- apply(seine.eq.avail, 1, mean, na.rm=TRUE)

# Fill out the seine eqivalents for the full assessment period using yearly
# area estimates were available, then falling back to the area averages
# where not available.

# Step 1: Available seine equivalents
seine.eq[rownames(seine.eq.avail), colnames(seine.eq.avail)] <- seine.eq.avail

# Step 2: Infill missing values with area-sepcific yearly average. Missing values
# could occur in a ragged fashion so each missing value will be indexed directly.
```

```
index <- as.matrix(subset(melt(is.na(seine.eq)), value == TRUE)[,1:2])
seine.eq[index] <- avg.seine.eq[index[ ,1]]

# Adjusted Effort ----------------------------------------------------
# Compute the adjusted effort for Canadian commercial fishery in seine
# equivalent boat days.
adj.effort <- structure(
  .Data = rep(NA, prod(d <- c(2,length(weeks.ak),n.yrs))),
  .Dim = d,
  .Dimnames = list(paste("Area", 3:4), weeks.ak, start.yr:end.yr)
)

for (week in adj.week) {
 adj.effort[,week,] <-  effort[paste("Area", 3:4) , 'seine', week, ] +
   effort[paste("Area", 3:4) , 'gillnet', week, ] * seine.eq[paste("Area", 3:4), ]
}

# Compute total adjusted effort by area and year.
tot.adj.effort <- apply(adj.effort, c(1,3), sum, na.rm=TRUE)

# Harvest & Exploitation Rates ---------------------------------------------
# For year out years outside the run reconstruction years (i.e,
# 1982-1995) a harvest rate to effort curve is used to predict harvest
# rates.

# Michaelis-Menten parameters for Effort vs HR relationship
parms <- list(
  'Area 3' = list(
    'Area Wide' = c('Vmax' = 1.43, 'Km' = 3635),
    'Alaskan' = c('Vmax' = 0.293, 'Km' = 1752)
  ),
  'Area 4' = list(
    'Area Wide' = c('Vmax' = 0.79, 'Km' = 2033),
    'Alaskan' = c('Vmax' = 0.352, 'Km' = 2813)
  )
)

hr.er <- array(
  data = NA, dim = c(2, nrow=5, ncol=n.yrs),
  dimnames=list(
    paste("Area", 3:4),
    c("Area HR", "CDN HR", "AK HR", "CDN ER", "Total ER"),
    as.character(start.yr:end.yr)
  )
)
yrs.all <- as.numeric(dimnames(hr.er)[[3]])

for (area in paste("Area", 3:4)) {

  yrs <- as.character(yrs.all[yrs.all < 1982 | yrs.all > 1995])

  # Estimate HR for infilled years based on the Effort to HR curve fitted parameters.
  v.max <- parms[[area]][['Area Wide']]['Vmax']
  Km <- parms[[area]][['Area Wide']]['Km']
  Hr[area, yrs] <- v.max * tot.adj.effort[area, yrs] / (tot.adj.effort[area, yrs] + Km)
  HrCDN[area, yrs] <-  Hr[area, yrs] * avgHrRatio[area]     # CND Harvest for infilled years
  HrAk[area, yrs] <- avgHrAk[area]
  rm(v.max, Km)

  # Revise Alaska Harvest rate for 1996 onwards
  yrs <- as.character(yrs.all[yrs.all > 1995])
  # yrs <- dimnames(hr.er)[[3]][as.numeric(dimnames(hr.er)[[3]]) > 1995]
  v.max <- parms[[area]][['Alaskan']]['Vmax']
  Km <- parms[[area]][['Alaskan']]['Km']
  HrAk[area, yrs] <- v.max * effortAK[yrs] / (effortAK[yrs] + Km)
  rm(v.max, Km)

  # Compute final values
  hr.er[area, "Area HR", ]  <- Hr[area, ]
  hr.er[area, "CDN HR", ]   <- HrCDN[area, ]
  hr.er[area, "AK HR", ]    <- HrAk[area, ]
```

```
    hr.er[area, "CDN ER", ]   <- HrCDN[area, ] * (1 - HrAk[area, ])
    hr.er[area, "Total ER", ] <- hr.er[area, "CDN ER", ] + HrAk[area, ]
  }


  # Save Results -------------------------------------------------------------

  if (!is.null(xlsx.out)) {
    if (file.exists(xlsx.out)) {
      # Updated specified xlsx file
      wb <- loadWorkbook(xlsx.out)
    } else{
      # Else create a new workbook
      wb <- createWorkbook()
    }
    s1 <- createStyle(numFmt = "0")
    s2 <- createStyle(numFmt = "0.000")
  }


  # Output: Pink ERs for TRTC ---------------------------------------------
  out <- data.frame(
    Year = start.yr:end.yr,
    "A3 CDN ER"   = hr.er['Area 3', 'CDN ER', ],
    "A3 TOTAL ER" = hr.er['Area 3', 'Total ER', ],
    "A4 CDN ER"   = hr.er['Area 4', 'CDN ER', ],
    "A4 TOTAL ER" = hr.er['Area 4', 'Total ER', ],
    "A5 CDN ER"   = hr.er['Area 4', 'CDN ER', ] * 0.5,
    "A5 TOTAL ER" = hr.er['Area 4', 'CDN ER', ] * 0.5 + HrAk['Area 4', ],
    check.names = FALSE,
    row.names = NULL
  )

  if (db.update) {
    # Use custom function to ensure data dimensions match
    TruncateWriteAccessTable(channel, PrepareChumPinkER(out, "Pink"), "INPUT Pink ERs")
  }

  if (exists('wb')) {
     # Add Diagnostics worksheet
    PinkChumModelDiagnostics(wb, effort, adj.effort, tot.adj.effort, effortAk, hr.er, adj.week)

    # Add final ERs
    sheet <- "Pink ERs for TRTC"
    BlankWorkSheet(wb, sheet)
    writeData(wb = wb, sheet = sheet, x = out,  startRow = 1, rowNames=FALSE, colNames = TRUE)
    addStyle(wb, sheet, s2, rows = 2:(nrow(out)-1), cols = 2:ncol(out), gridExpand = TRUE)
  }

  # Import: Chum ERs for TRTC ---------------------------------------------

  # Read in the Chum HR for 1982-present
  # worksheet <- "Chum HR Summary"  # Sheet name in the Pink and Chum Excel
  worksheet <- "Summary"
  dat <- read.xlsx(xlsxFile = xlsx.Chum, sheet = worksheet, startRow = 3)
  colnames(dat)[1] <- "Year"

  dat <- subset(dat, Year >= 1982 & Year <= end.yr)

  # Check that imported data
  if (min(dat$Year) != 1982) stop("Error in Chum HR data, min year is not 1982")
  if (max(dat$Year) < end.yr) stop("Error in Chum HR data, max year not supported by 'end.yr'")

  Chum.hr <- matrix(NA, nrow=3, ncol=n.yrs, dimnames = list(paste("Area", 3:5),
as.character(start.yr:end.yr)))
  yrs <- as.character(dat$Year)
  Chum.hr['Area 3', yrs] <- dat$Nass
  Chum.hr['Area 4', yrs] <- dat$Skeena
  Chum.hr['Area 5', yrs] <- dat$Area.5

  # Reset output values for Chum analyses
```

```
  out[ ,-1] <- NA


  # Historical Chum ERs (1954-1981) -----------------------------------------
  # For start.yr to 1981 Chum ERs are simply assumed to
  yrs <- as.character(start.yr:1981)
  i <- which(out$Year %in% yrs)
  out[i,"A3 CDN ER"]    <- hr.er['Area 3','CDN ER',yrs]     # Pink ER
  out[i,"A3 TOTAL ER"]  <- hr.er['Area 3','Total ER',yrs]   # Pink ER
  out[i,"A4 CDN ER"]    <- hr.er['Area 4','CDN ER',yrs]     # Pink ER
  out[i, "A4 TOTAL ER"] <- hr.er['Area 4','Total ER',yrs]   # Pink ER
  out[i,"A5 CDN ER"]    <- hr.er['Area 4','CDN ER',yrs] * 0.5 # Pink
  out[i,"A5 TOTAL ER"]  <- hr.er['Area 4','CDN ER',yrs] * 0.5 + HrAk['Area 4',yrs]    # Pink

  # Recent Chum ERs (1982 - present) -------------------------------------
  # Next the recent years (i.e., avaliable in the BC Hail data base) we
  # we use a combination of Chum Harvest rates (from the Chum model) and
  # adjust for US (Alaska) interceptions by using Pink Alaska ERs as a
  # proxy of Chum (see #24 for further details.)
  yrs <- as.character(seq(start.yr.hail, end.yr))
  i <- which(out$Year %in% yrs)

  #--- Area 3 ER ---
  er.ak <- hr.er['Area 3','Total ER',yrs] - hr.er['Area 3','CDN ER',yrs]  # Alaska Chum ER, based on Alaska
Pink ER
  out[i,"A3 CDN ER"]    <- Chum.hr['Area 3', yrs] * (1 - er.ak)           # Adjust Canadian ER for US
interceptions
  out[i,"A3 TOTAL ER"]  <- out[i,"A3 CDN ER"] + er.ak                     # Total ER is Canadian + US

  #--- Area 4 ER ---
  er.ak <- hr.er['Area 4','Total ER',yrs] - hr.er['Area 4','CDN ER',yrs]
  out[i,"A4 CDN ER"]    <- Chum.hr['Area 4', yrs] * (1 - er.ak)
  out[i,"A4 TOTAL ER"]  <- out[i,"A4 CDN ER"] + er.ak

  #--- Area 5 ER ---
  er.ak <- hr.er['Area 4','Total ER',yrs] - hr.er['Area 4','CDN ER',yrs]
  out[i,"A5 CDN ER"]    <- Chum.hr['Area 5', yrs] * (1 - er.ak)
  out[i,"A5 TOTAL ER"]  <- out[i,"A5 CDN ER"]  + er.ak

  # Output: Chum ERs for TRTC --------------------------------------------

   # Update NCCSDB
  if (db.update) {
    # Use custom function to ensure data dimensions match
    TruncateWriteAccessTable(channel, PrepareChumPinkER(out, "Chum"), "INPUT Chum ERs")
  }

  # Update Excel Output
  if (exists('wb')) {
    sheet <- "Chum ERs for TRTC"
    BlankWorkSheet(wb, sheet)
    writeData(wb = wb, sheet = sheet, x = out,  startRow = 1, rowNames=FALSE, colNames = TRUE)
    addStyle(wb, sheet, s2, rows = 2:(nrow(out)), cols = 2:ncol(out), gridExpand = TRUE)
  }

  # Save XLSX ---------------------------------------------------------
  if (exists('wb')) {
    saveWorkbook(wb, file = xlsx.out, overwrite = TRUE)
  }
}
```