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Assessment of the Interior Fraser Coho Salmon (*Oncorhynchus kisutch*) Management Unit Relative to the 2006 Conservation Strategy Recovery Objectives

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Interior Fraser Coho is the name for the management unit (MU) which refers to the Coho Salmon (*Oncorhynchus kisutch*) that return to the Fraser River and tributaries upstream of Hells Gate in the Fraser Canyon. In response to low abundance of southern BC Coho Salmon stocks, fisheries that intercept Interior Fraser Coho have been restricted since 1998. This document describes the fishery management actions that have been taken since 2006 to meet the 2006 Conservation Strategy recovery objectives for Interior Fraser Coho, provides an assessment of current status of the MU against these objectives, quantifies annual exploitation rates and the level of uncertainty in these estimates, and provides estimates of the probability of achieving the 2006 Conservation Strategy Recovery Objectives at a range of potential exploitation rates.

Given that Wild Salmon Policy (WSP) benchmarks are not currently available for Interior Fraser Coho, the status of Interior Fraser Coho was assessed against two ‘short term’ and one ‘long term’ recovery objective originally proposed by the Interior Fraser Coho Recovery Team (IFCRT 2006). Short-term objective #1 consists of maintaining a minimum of 1,000 naturally spawning wild Coho Salmon (3-year geometric mean) in at least half of the 11 subpopulations that have been proposed within the five conservation units (CUs) (IFCRT 2006), while the long-term objective consists of maintaining 1,000 or more wild Coho Salmon in all 11 subpopulations. Our analyses showed that escapement levels of 20,000 and 40,000 spawners, respectively, would result in near 100% probability that these two objectives would be met. Generational average escapements for the Interior Fraser Coho aggregate exceeded 20,000 wild adults in every year from 2008 onward, but exceeded 40,000 wild adults in only the two most recent return years (2012 and 2013).

Short-term objective #2 focuses on maintaining the productivity of Interior Fraser Coho. After controlling for brood escapement, we found strong evidence for two distinct periods of productivity: a relatively high productivity period during 1978-1993 return years, and a low productivity period during 1994-2012. There is no evidence that Interior Fraser Coho have moved above the ‘low’ productivity’ regime that has persisted since 1994 (return year).

Modelled estimates of exploitation rates averaged 10% during 1998-2012. From 1986-1997, the average exploitation rate was nearly seven fold higher. The reliability of exploitation rate estimates for Interior Fraser Coho from 1998 onward is uncertain, owing primarily to uncertainty around the assumption that base period effort and exploitation rate (16-26 years ago) are representative of current effort and exploitation rate.

A model selection analysis indicated that the Ricker model best explained the stock-recruitment relationship for Interior Fraser Coho during the period of low productivity (1994-2012), and was used to form the basis of the harvest impact projections. Assuming low productivity, there is a strong trade-off between the probability of achieving the short-term objective of 20,000 spawners (3-year geometric mean) and exploitation rate. The probability of meeting the long-term objective of 40,000 spawners at low productivity is low regardless of exploitation rate. A declining population trend was predicted at exploitation rates exceeding 30%. Assuming a continuation of the 1994-2012 low productivity regime, there appears to be limited potential for recovering the MU to abundance levels higher than 20,000-40,000 spawners. A relatively low escapement target within this range (20,000 spawners) could maximize harvest opportunities for other stocks while still maintaining Interior Fraser Coho at a relatively productive point along the stock-recruitment curve. However, this represents a riskier management strategy compared to a strategy of maximizing escapement given current productivity.

This assessment must be considered as preliminary and not equivalent to a Wild Salmon Policy (WSP) status assessment since it relies primarily on the IFCRT recovery objectives and not formal WSP benchmarks.

Évaluation de l'unité de gestion du saumon coho (Oncorhynchus kisutch) du Fraser intérieur par rapport aux objectifs de rétablissement de la stratégie de conservation de 2006

RÉSUMÉ

Saumon coho du Fraser intérieur est le nom donné à l'unité de gestion (UG) où les saumons coho (*Oncorhynchus kisutch*) remontent dans le fleuve Fraser et ses tributaires en amont de Hells Gate, dans le canyon du Fraser. En raison de la faible abondance des stocks de saumon coho dans le sud de la Colombie-Britannique, les pêches dans le cadre desquelles on intercepte le saumon coho du Fraser intérieur sont restreintes depuis 1998. Le présent document décrit les mesures de gestion des pêches qui ont été prises depuis 2006 en vue d'atteindre les objectifs de rétablissement de la stratégie de conversation de 2006, fournit une évaluation de l'état actuel de l'UG par rapport à ces objectifs, quantifie les taux d'exploitation annuels et le niveau d'incertitude de ces estimations et évalue la probabilité d'atteindre les objectifs de la stratégie de conservation de 2006 en appliquant un éventail de taux d'exploitation possibles.

Comme les points de référence de la Politique concernant le saumon sauvage (PSS) ne sont actuellement pas disponibles pour le saumon coho du Fraser intérieur, la situation du saumon coho du Fraser Intérieur a été évaluée par rapport à deux objectifs de rétablissement ‘à court terme’ et un objectif ‘à long terme’, initialement proposés par l'équipe de rétablissement du saumon coho du Fraser intérieur (ÉRCFI 2006). Le premier objectif à court terme consiste à maintenir un minimum de 1 000 saumons coho sauvages qui se reproduisent naturellement (moyenne géométrique sur 3 ans) dans au moins la moitié des 11 sous-populations proposées dans les cinq unités de conservation (UC) (ÉRCFI 2006), tandis que l'objectif à long terme est de maintenir au moins 1 000 saumons coho sauvages dans les 11 sous-populations. Nos analyses ont démontré que des niveaux d'échappée de 20 000 et de 40 000 géniteurs, respectivement, entraîneraient une probabilité de près de 100 % que l'on atteigne les deux objectifs. Les échappées générationnelles moyennes des populations de saumon coho du Fraser intérieur en comigration dépassent les 20 000 adultes sauvages chaque année depuis 2008, mais ont dépassé les 40 000 adultes sauvages seulement au cours des deux dernières années de montaison (2012 et 2013).

Le deuxième objectif à court terme vise principalement à maintenir la productivité du saumon coho du Fraser intérieur. Après avoir pris en considération les échappées pendant l’année d’éclosion, nous avons trouvé des preuves solides de deux périodes de productivité distinctes : une période de productivité relativement élevée durant les années de montaison de 1978 à 1993 et une période de faible productivité de 1994 à 2012. Rien ne permet de prouver que le saumon coho du Fraser intérieur n'est plus dans la période de faible productivité qui persiste depuis 1994 (année de montaison).

Des estimations modélisées des taux d'exploitation étaient en moyenne de 10 % durant la période de 1998 à 2012. De 1986 à 1997, le taux d'exploitation moyen était près de sept fois plus élevé. La fiabilité des estimations des taux d'exploitation du saumon coho du Fraser intérieur à partir de 1998 est incertaine, principalement en raison de l'incertitude entourant l'hypothèse selon laquelle l'effort et le taux d'exploitation de la période de base (il y a entre 16 et 26 ans) sont représentatifs du niveau d'effort et du taux d'exploitation actuels.

Une analyse des choix de modèles indique que le modèle Ricker est celui qui explique le mieux la relation stock-recrutement du saumon coho du Fraser intérieur pendant la période de faible productivité (de 1994 à 2012) et a été utilisée pour constituer la base des prévisions des répercussions de la pêche. En supposant que la productivité est faible, on remarque un

compromis très important entre la probabilité d'atteindre l'objectif à court terme de 20 000 géniteurs (moyenne géométrique sur 3 ans) et le taux d'exploitation. La probabilité d'atteindre l'objectif à long terme de 40 000 géniteurs en période de faible productivité est faible, peu importe le taux d'exploitation. On prévoit un déclin de la population si le taux d'exploitation dépasse les 30 %. En supposant que la période de faible productivité de 1994 à 2012 se poursuit, il semble y avoir peu de chance que l'UG se rétablisse et atteigne des niveaux d'abondance de plus de 20 000 à 40 000 géniteurs. Une cible d'échappée relativement faible à l'intérieur de cette fourchette (20 000 géniteurs) pourrait maximiser les possibilités de pêche d'autres stocks tout en maintenant le saumon coho du Fraser intérieur à un point le long de la courbe stock-recrutement relativement productif. Il s'agit toutefois d'une stratégie de gestion plus risquée comparativement à une stratégie visant à maximiser l'échappée étant donné la productivité actuelle.

Cette évaluation doit être considérée comme préliminaire et n'équivaut pas à une évaluation de la situation de la Politique concernant le saumon sauvage puisqu'elle s'appuie principalement sur les objectifs de rétablissement de l'ÉRCFI et non sur les points de référence officiels de la Politique.

1. INTRODUCTION

The Coho Salmon (*Oncorhynchus kisutch*) is one of six species of Pacific Salmon which are native to Canada. Interior Fraser Coho is the name for the management unit (MU) which refers to the Coho Salmon that return to the Fraser River and tributaries upstream of Hells Gate in the Fraser Canyon. Population structure exists within the MU, and five Conservation Units (CUs) have been proposed based on genetic information (Holtby and Ciruna (2007). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) adopted the Interior Fraser Coho management unit definition for a designatable unit (DU) with a similar name for their assessment of risk of extirpation. In May 2002 COSEWIC designated Interior Fraser Coho as endangered (COSEWIC 2002) based on information presented by Irvine (2002). The DFO recently completed a pre-COSEWIC assessment of Interior Fraser Coho (Decker and Irvine 2013) in anticipation of a status reassessment by COSEWIC in 2014-2015. DFO is also planning an assessment of Interior Fraser Coho under its Wild Salmon Policy (WSP) sometime during 2014-15.

In 2006 DFO published a conservation strategy outlining recovery objectives for Interior Fraser Coho (IFCRT 2006). DFO Science Branch conducted this assessment of the Interior Fraser Coho Salmon management unit to determine its current status and what would be the impact to the management unit of increased harvest of Fraser River Sockeye Salmon. The conclusions and advice presented here will be used to inform fishery planning and the development of the Integrated Fishery Management Plan (IFMP) for the 2014 season. This assessment represents the most current management advice for Interior Fraser Coho until such time as a WSP assessment is completed.

The objectives of this working paper are to:

- Describe the fishery management actions that have been taken since 2006 to meet the 2006 Conservation Strategy recovery objectives.
- Quantify aggregate, population and subpopulation metrics for abundance, distribution and productivity.
- Compare current population metrics to those outlined in the 2006 Conservation Strategy recovery objectives.
- Quantify annual exploitation rates and the level of uncertainty in these estimates.
- Estimate the probability of achieving the 2006 Conservation Strategy Recovery Objectives at a range of potential exploitation rates.

1.1. MANAGEMENT UNIT DESCRIPTION

1.1.1. Population Structure

Beacham et al. (2011) examined variation at 17 microsatellite loci in their recent review of the population structure of North American Coho Salmon. Coho Salmon from the Interior Fraser River were distinct from other Coho Salmon and among the least genetically diverse of the various populations examined.

Population structure within the Interior Fraser was geographically based, aligning with the five CUs described by Holtby and Ciruna (2007) (Figure 1). Beacham et al. (2011) evaluated the distribution of genetic variation in Coho Salmon in North America using a gene diversity analysis that was structured among regions, among populations within regions, and among sampling years within populations. They found that Coho Salmon from the North Thompson River drainage clustered together in 63% of dendrograms evaluated while the clustering percentages were 36%, 92%, and 55% for the South Thompson River, lower Thompson River, and middle Fraser River regions respectively (Figure 2). Coho Salmon from the single location surveyed in the Fraser River canyon (Nahatlatch River) were distinct both from upstream populations and those of the lower Fraser River (Beacham et al. 2011). Migration among CUs does occur, but it is sufficiently restricted to permit local adaptations to occur (Irvine et al. 2000). Genetic diversity is three to 10 times greater among CUs compared to variation among spawning groups (occupying different tributaries) within each CU.

While further subdivision of the Interior Fraser Coho aggregate beyond the suggested five CUs does not appear warranted based on existing genetic information, each CU but one (Nahatlatch River represents the only known spawning location for the Fraser Canyon CU) occupies a vast drainage area, and gaps remain in the baseline genetic samples, particularly for spawning areas in the Middle/Upper Fraser watershed and in some of the more remote Thompson River tributaries (IFCRT 2006). The geographic size of the CUs is of concern because it is known that migration or dispersal among spawning groups (i.e., straying) occurs at a decreasing rate with distance from the natal stream (Quinn 1993), and that the arrangement of suitable spawning habitat (e.g., inter-patch distance and connectivity) plays a central role in metapopulation dynamics, and can affect the rate of recolonization of spawning locations following local extirpation and the overall risk of extinction (Schtickzelle and Quinn 2007). To address demographic considerations and the possibility of spatial structure within each CU, and to provide a framework for conservation and recovery planning, the Interior Fraser Coho Recovery Team (IFCRT) proposed that the Interior Fraser Coho aggregate be further delineated into 1-3 subpopulations within each population (CU), which amounted to 11 subpopulations in total. The IFCRT delineated subpopulations based on large watersheds or lakes, the presence of partial barriers to migration, and limited genetic evidence. Where possible, we have followed the IFCRT's in lead and applied our assessment of current status and simulations of different management scenarios at the subpopulation level in addition to the CU and aggregate levels.

1.1.2. Fisheries

Prior to 1998, Interior Fraser Coho were intercepted in a broad range of fisheries throughout the marine areas of British Columbia and Washington State as well as fisheries within the Fraser River. Coho fisheries are evaluated through the Coho Technical Committee (CohoTC), a bi-lateral technical committee which reports to the Pacific Salmon Commission (PSC). The fishery evaluations are conducted using a Coho Fisheries Regulation Assessment Model (Coho FRAM). The Coho FRAM is an accounting model that evaluates 246 stocks in 198 fisheries over 5 time periods. It can be used to estimate catch and escapement based on forecast abundance and planned fisheries (forward FRAM) or it can be used to reconstruct ocean abundance from observed escapements and catch (backward FRAM). The model is founded on a Base Period, currently 1986 to 1992, and scales it according to current stock abundances and fisheries impacts. The exploitation rate (ER) data that were assembled for the Coho FRAM Base Period (PSC-JCohoTC 2013) can be used to generalize the distribution of harvest. According to these data, the largest portion of the harvest of Interior Fraser Coho was by the commercial troll fishery off southwest Vancouver Island (Table 1). The next largest portion was harvested by the commercial troll fishery off the northwest coast of Vancouver Island.

From 1998 to 2002, in response to the low abundance of southern BC Coho Salmon stocks, fisheries that intercepted Interior Fraser Coho were severely restricted. This resulted in greatly reduced exploitation rates (see Section 3.2). Since 2003, fishing restrictions have been eased somewhat compared to 1998-2002, but remain much more restrictive than the pre-1998 period (Decker and Irvine 2013). In recent years the distribution of interceptions has also been much different compared to the period before 1998. Since 2004, due to reductions in Canadian fisheries, most of the Interior Fraser Coho harvest now takes place in US commercial fisheries.

1.1.3. Management Actions Taken to Reduce Mortality

Beginning in 1998, significant fishery management measures were taken in order to reduce the fishery-related mortality on southern BC Coho Salmon stocks and on Interior Fraser Coho in particular. With the application of these measures, the fishing mortality on Interior Fraser Coho has been managed in-season for an ER cap of 13%. Under the 2008 PST Southern Coho Agreement, for a Management Unit (MU) with a 'low' status (for the recent status of the Interior Fraser Coho MU, see the Pacific Salmon Treaty; PSC-JCohoTC 2013), the ER cap is 20%. The producing country (Canada in this case) is expected to bear a greater share of the conservation responsibility for MUs in low status. The intercepting country (the US in this case) is not required to reduce its impact below a 10% ER. In the early 2000s the Canadian Minister of Fisheries established a domestic ER cap of 3% for the Interior Fraser Coho MU.

Since 1998, there have been no commercial or recreational fisheries in BC targeting Interior Fraser Coho. Furthermore, for fisheries occurring in areas and dates where and when Interior Fraser Coho might be present, commercial catch has been restricted to non-retention of Coho Salmon during fishing for other salmon species. Similarly, First Nations and recreational catch has been restricted to non-retention of wild Coho Salmon during fishing for other species, and during fisheries targeting hatchery-origin Coho Salmon. Retention of non-hatchery-origin Coho Salmon in southern BC has only been permitted in terminal areas where Interior Fraser Coho have been identified as being abundant through enumeration using a weir. Harvests to date in these terminal fisheries have been very modest (10 to 50 Coho Salmon) in some years.

To reduce the incidental mortality of Coho Salmon, several mandatory selective fishing practices are currently in place for southern BC fisheries. These include, barbless hooks for reduced injury, revival tanks for recovery of fish prior to release, and brailing of catch from purse seine bunts to allow for live-sorting. These practices are required, except in terminal areas and after a date when Interior Fraser Coho are no longer expected to be in the area (e.g. after September 30th).

See Appendix A for a summary of the management actions taken to reduce the fishery-related mortality on Interior Fraser Coho since 1998 through to 2013.

1.2. APPROPRIATE METRICS AND OBJECTIVES FOR EVALUATING STATUS

Holt et al. (2009) identified quantifiable metrics (criteria) of biological status and benchmarks for the assessment of status of Pacific Salmon Conservation Units (CUs) under DFO's Wild Salmon Policy (DFO 2005), and recommended a multi-criteria approach for assessing status that considered information on relative abundances, change in abundance over time, distribution of spawners, and fishing mortality. Holt et al. concluded that interpretation of status across multiple metrics can provide a more complete picture of population status. Grant and Pestal (2012) recently assessed the status of Fraser River Sockeye Salmon CUs using metrics and benchmarks recommended by Holt et al. (2009). The establishment of benchmarks or recovery objectives for Interior Fraser Coho CUs poses particular challenges. Unlike most Fraser Sockeye Salmon CUs, each Interior Fraser Coho CU (with the exception of the Fraser Canyon CU) occupies a very large geographic area, with spawning groups widely distributed among many locations (Bradford and Wood 2004). As well, escapement monitoring for Interior Fraser Coho has also been much less comprehensive and consistent over time compared to that for Fraser Sockeye Salmon. The status of Interior Fraser Coho CUs has yet to be assessed under the WSP, and no benchmarks or reference points have been formally adopted for the CUs or for the Interior Fraser aggregate[1]. The CohoTC is currently working on WSP benchmarks and management unit reference points for Strait of Georgia Coho Salmon populations and Fraser River management units, including Interior Fraser Coho, and are tentatively scheduled for assessment in 2014-15.

1.2.1. Rate of Change in Abundance

The use of multiple change in abundance metrics and their interpretation in the context of ancillary information was recommended for Pacific Salmon status assessments by Holt et al. (2009), and in a recent process to evaluate the status of Fraser Sockeye Salmon CUs (Grant and Pestal 2012). Change in abundance over three generations of an organism's life cycle (or 10 years, whichever is longer) is a key metric in COSEWIC status assessments (COSEWIC 2010). Rate of change in abundance is an important metric for this status assessment because the response of Interior Fraser Coho (i.e., increases or declines in abundance) to management changes since 1998 is of primary interest. We examined the average annual and total rate of change in escapement for the most recent one, three, and five generations of Interior Fraser Coho, with five generations (1998-2012) encompassing the entire post-1998 recovery period.

1.2.2. Distribution

Spatial distribution is another commonly used criteria for assessing the status of salmon populations (Peacock and Holt 2010), and has been recommended as a metric for assessing salmon CUs under the WSP (Holt et al. 2009). Conserving as many spawning groups as possible enhances the resilience of salmon populations in two ways: it maintains the genotypic and phenotypic diversity that has developed over time among groups of salmon spawning in different areas or streams, and it reduces the vulnerability of populations to anthropocentric or natural disturbances or catastrophic events in localized areas (see Peacock and Holt 2010 for a more detailed discussion). Distribution is particularly relevant to the status of Interior Fraser Coho because of the large geographic area encompassed by each CU, and the likelihood of fragmentation of individual CUs into smaller isolated groups vulnerable to Allee effects (e.g. Chen et al. 2002). We examined the recent distribution of Interior Fraser Coho and the relationship between distribution and escapement at both the aggregate and CU level.

1.2.3. IFCRT Recovery Objectives

Given that WSP benchmarks are not currently available for Interior Fraser Coho, for the purposes of this interim assessment, we have elected to evaluate the status of Interior Fraser Coho against two 'short-term' and one 'long-term' recovery objective originally proposed by the IFCRT (2006). In 2006 the IFCRT proposed two short-term and six possible long-term recovery objectives to address the overall goal of recovering Interior Fraser Coho. In relation to WSP terminology (DFO 2005) the IFCRT suggested that their short-term and long-term recovery objectives were analogous to moving a population from the Red Zone into the Amber Zone, and from the Amber Zone into the Green Zone, respectively (IFCRT 2006).

The IFCRT's short-term objectives address the recovery goal of 'securing the long-term viability of naturally spawning Coho Salmon within the interior Fraser River watershed' (IFCRT 2006). 'Objective #1' provides a quantifiable objective/benchmark against which abundance metrics can be assessed to determine status. It consists of maintaining a minimum of 1,000 naturally spawning wild Coho Salmon (3-year geometric mean) in at least half of the subpopulations that they proposed for each of the five CUs (IFCRT 2006). This amounts to maintaining

[1] Benchmarks and recovery objectives for Interior Fraser Coho proposed in earlier studies are summarized in Decker and Irvine 2013.

escapements of >1,000 wild fish in seven of the 11 subpopulations. This approach was modelled after the US model for Evolutionarily Significant Unit (ESU) viability (McElhaney et al. 2000) was based on consideration of the effective population size necessary to conserve genetic diversity (Allendorf and Ryman 2002; Waples 2002), and the results of simulation modelling for several other Pacific Salmon populations that suggested that starting populations larger than 1,000 individuals had a low risk of extirpation and a reasonable expectation of growth, providing that productivity did not remain excessively low (IFCRT 2006).

Although the IFCRT applies the criteria of >1,000 individuals at the subpopulation, this was not based on any specific scientific criteria (Bradford and Wood 2004). In reviewing the September 2004 draft of the IFCRT recovery plan, Bradford and Wood note that gene flow among the proposed subpopulations is likely sufficient (>10 effective migrants/generation) within four of the five CUs (the Fraser Canyon CU occupies only one stream) to allow genetic conservation targets to be set at the CU level. They note that the majority of the proposed subpopulations represent metapopulations because they consist of a number of spawning aggregations or demes, and that metapopulations have a greater probability of persistence due to straying and asynchrony in population fluctuations among demes as a result of spatial variation in environmental conditions. Bradford and Wood also point out that the empirical data indicate that Interior Fraser Coho are capable of achieving positive population growth (i.e., productivity > 1 recruit/spawner) at very low marine survival rates[2], and when generational mean abundance of individual subpopulations has fallen below 1000 spawners.

The IFCRT (2006) chose to apply their criteria of >1000 individuals at the subpopulation level because they were concerned about the large geographic area encompassed by each CU, and the potential vulnerability to Allee effects if spawning groups become excessively fragmented. They reasoned that by ensuring that more than one subpopulation remain viable within each CU, this would provide insurance against catastrophic events, and would likely result in protection of a greater proportion of the biodiversity of the CU as a whole. An empirical analysis (1975-2003 data), conducted by the IFCRT (2006) indicated that an escapement of ~20,000-25,000 adults for the Interior Fraser aggregate as a whole would be required, on average, to meet the objective of 1,000 or more individuals in at least half of the subpopulations within each of the five CUs. This objective exceeds 7,000 spawners (i.e., seven subpopulations with 1,000 or more individuals each) because the subpopulations differ in productivity and potential carrying capacity, and they would not all be expected to have the same status at any one time. However, as noted by Bradford and Wood (2004), any aggregate-level escapement target intended to meet this recovery objective depends on the observed pattern of relative abundance among subpopulations continuing in the future (Bradford and Wood 2004).

The IFCRT's 'short-term objective #2' focuses on 'maintaining the productivity of Interior Fraser Coho through the development of harvest management plans that are sensitive to fluctuations in ocean conditions (i.e., productivity), protection and rehabilitation of important habitats, and ensuring that enhancement is consistent with the recovery goal' (IFCRT 2006). Although the IFCRT did not recommend specific productivity targets, their emphasis on management plans that explicitly consider productivity is relevant to this assessment. Wherever possible, we have attempted to incorporate the effects of variable productivity in our assessment of current status of Interior Fraser Coho (*Section 2*) and in the modelling exercises to estimate the probability of achieving abundance-based recovery objectives at a range of potential exploitation rates (*Section 4*).

[2] This assumes smolt-adult survival estimates for Strait of Georgia wild Coho Salmon indicator stocks are accurate and unbiased predictors of Interior Fraser Coho survivals (see Decker and Irvine 2013, Section 11.5).

The IFCRT's long-term objectives address the goal of recovering Interior Fraser Coho so that other societal objectives can be achieved (e.g., direct harvest in terminal areas, or increases in allowable by-catch in downstream fisheries; IFCRT 2006). Of the six long-term recovery objectives proposed by the IFCRT (2006), we elected to assess Interior Fraser Coho against only their first objective of achieving three-year geometric mean escapements exceeding 1,000 naturally spawning wild Coho salmon in all 11 subpopulations representing the five CUs. The remaining five long-term objectives either did not provide a quantifiable objective/benchmark against which abundance metrics could be assessed, or data were insufficient to allow for such an assessment. These objectives consisted of: 1) recovering each of the five CUs to the maximum sustainable yield (MSY) on an average annual basis given existing environmental conditions, 2) recovering each CU to its maximum historic abundance level, 3) recovering each CU to a level where the freshwater productive capacity is optimized (e.g., maximum smolts/km), 4) increasing adult returns so that sufficient marine-origin nutrients enter the drainage area of each CU to optimize ecosystem function, and 5) recovering Interior Fraser Coho to a level that will allow for harvesting at higher levels than are currently allowed.

2. ASSESSMENT OF CURRENT STATUS

2.1. METHODS

2.1.1. Escapement Data

For Interior Fraser Coho, the majority of escapement (number of returning adults escaping marine and freshwater fisheries and returning to natal spawning streams) estimates are derived from visual observations of adults on the spawning grounds (aerial or ground surveys; ideally incorporating multiple surveys spanning the entire period). Uncalibrated visual counts will underestimate escapement because not all spawners present are seen and because not all fish that spawn in an area are present during any survey. In most cases, escapement estimates are derived from visual counts using either the area-under-the-curve (AUC) method (English et al. 1992), which incorporates additional information about detection probability and survey life, or the expanded peak count method where raw counts of salmon are expanded based on calibration studies where visual surveys are paired with a more accurate method such as a counting fence, resistivity counter, or mark-recapture study. These more accurate methods are also used in place of visual surveys on some streams.

Although escapement estimates exist for some Interior Fraser streams as far back as 1951, older estimates (1951-1974) are of unknown accuracy and precision. Consequently, pre-1975 estimates are of little use for analyses of changes in abundance over time. During 1975-1997 many of the tributaries within the North Thompson and South Thompson CUs were surveyed in most years. From 1984-1997, annual escapement surveys were extended to four additional streams (Coldwater, Spius, Deadman, and Bonaparte) representing the bulk of escapement for the Lower Thompson CU. Prior to 1998, escapement surveys were often conducted opportunistically by Fishery Officers and other DFO staff rather than as a part of monitoring program designed and conducted by stock assessment staff, and the precision and accuracy of these estimates varies considerably (Irvine et al. 1999a and 1999b provide detailed descriptions). For the Middle/Upper Fraser and Fraser Canyon (Nahatlatch River) CUs, no reliable survey data are available prior to 1998 for the majority of streams.

In 1998, as part of the recovery effort for Interior Fraser Coho, an expanded and more rigorous escapement survey program was implemented: the number of streams surveyed annually increased from an average of 56 during 1975-1997, to an average of 86 during 1998-2012. This expanded effort included the Nahatlatch River (Fraser Canyon CU) and 10-21 streams in the

Middle/Upper Fraser CU. In addition, the number of surveys conducted each year for an individual stream generally increased, and more accurate methods such as counting fences and mark-recapture studies were employed with greater frequency (R. Bailey, Fisheries & Oceans Canada, Kamloops, BC, personal communication, 2013).

In order to assess escapement trends for individual CUs and for the Interior Fraser Coho aggregate it is necessary to adjust (generally upwards) estimates from earlier years when less rigorous methods were employed, and to infill estimates for unsurveyed streams and missing years. This was accomplished by various means in previous assessments (e.g., Irvine et al. 2001; Simpson et al. 2001, IFCRT 2006). In the most recent assessment of Interior Fraser Coho, Decker and Irvine (2013) used a reconstruction of the escapement time series completed by the IFCRT for 1975-1997 (see IFCRT 2006, Appendix 3 for a detailed description of their methods) and their own reconstruction for 1998-2011 that was based on the IFCRT's methods (see Decker and Irvine 2013, Section 11.1). For this assessment, we used the same escapement time series as Decker and Irvine (2013) for 1975-2011 and infilled estimates for unsurveyed streams in 2012 using their approach.

It is important to note that escapement estimates for the Middle/Upper Fraser and Fraser Canyon CUs for 1975-1997, and for the Lower Thompson for 1975-1983 (Table 2) are based entirely on average ratios of abundance in these CUs to combined abundance in the North and South Thompson CUs during 1998-2000 (IFCRT 2006, Appendix 3). This introduces a substantial degree of uncertainty in the reliably of the earlier portion of the time series for these CUs and for the aggregate as a whole. Annual escapements for the North and South Thompson CUs combined were a good predictor of escapements for the Middle/Upper Fraser CU during 1998-2012 (R^2=0.78, n=15), suggesting that this approach could provide reasonable approximations of escapement for the Middle/Upper Fraser CU for earlier years, but the same relationship was much weaker for the Fraser Canyon (R^2=0.19) and Lower Thompson CUs (1984-2012, R^2=0.09, n=29), suggesting that approximated escapements for the latter two CUs for earlier years are highly uncertain. In addition, estimates of total escapement for individual CUs and for the Interior Fraser aggregate are biased low to some degree for all years in the time series because not all Interior Fraser streams to which Coho Salmon returned were surveyed. One important source of uncertainty is the Middle/Upper Fraser CU for which the extent of distribution is not known, and relatively few streams were surveyed on an annual basis (see Decker and Irvine, Section 11.1, last par.). The major sources of uncertainty in Interior Fraser Coho escapement estimates are summarized in Table 3.

2.1.2. Hatchery Production

Hatchery production of Interior Fraser Coho Salmon began in the late 1970s and the early 1980s for fry and smolts, respectively. Annual fry releases ranged from 1.5-2.5 million annually during the peak of production in the 1980s, but have remained under 400,000 since 2000 (Regional Mark Information System Database (online database), Regional Mark Processing Center, Pacific States Marine Fisheries Commission, Portland, Oregon).

Annual smolt releases peaked during 1999-2002 at 350,000-400,000, and declined to 200,000-250,000 in recent years. There are no large production facilities for Coho Salmon in the Interior Fraser. At the peak of production there were ~13 small enhancement projects. Since the late 1990's, enhancement for Interior Fraser Coho has taken one of three forms: 1) conservation enhancement, used to protect demes that are at risk of extirpation (e.g., Salmon River); 2) assessment enhancement, where releases of CWT marked fish provide information for assessment of survival and exploitation rates and ocean distribution; and 3) rebuilding enhancement, where hatchery supplementation is used to increase escapements

(IFCRT 2006). Enhancement activities are described in more detail by Irvine et al. (1999a, 2000) and the IFCRT (2006).

The majority of hatchery-origin Coho Salmon returning to the Interior Fraser spawn naturally in the wild. As a result, these first generation hatchery fish are included in escapement surveys of wild fish in enhanced streams. Prior to 1998, 21% of hatchery fry and 56% of hatchery smolts on average were marked prior to release (removal of adipose fin). After 1998, marking rates were reduced to averages of 2% and 23% for fry and smolts, respectively. Stock assessment and hatchery staff record the presence or absence of an adipose fin for live adults and carcasses that are encountered at counting fences and during hatchery brood collections or foot surveys. Based on the proportion of released hatchery smolts that are marked, and the proportion of returning adults with marks, discrete estimates of escapement can be generated for Coho Salmon that are the progeny of fish that spawned in the wild and Coho Salmon that originated from a hatchery. It should be noted, however, that estimates of the proportions of hatchery-origin Coho Salmon at the CU and Interior Fraser aggregate levels are biased low to some degree because hatchery fish are known to stray to unenhanced streams for which it is assumed wild-origin fish contributed 100% of escapements (Table 3). This results in biased-high estimates of wild Coho Salmon escapements. It should also be noted that, under the Wild Salmon Policy (DFO 2005), some progeny of natural spawners are not “sufficiently wild” to qualify as wild salmon, since the WSP defines wild salmon as having spent their entire life cycle in the wild and originating from parents that were also produced by natural spawning and continuously living in the wild. This also contributes to biased-high estimates of wild Coho Salmon escapements. Unless indicated otherwise, we assessed abundance and trends in abundance for Interior Fraser Coho based on escapements of natural-origin fish only.

2.1.3. Recent Abundance, Total Return and Productivity

To describe recent abundance (escapement) for individual CUs and for the Interior Fraser Coho aggregate, we used the 3-year geometric mean. This metric represents average abundance per generation (Interior Fraser Coho predominately have a 3-year life history). We used the geometric mean to place greater weight on years of lesser abundance so that status was not unduly affected by a large return in a single year. To smooth the abundance time series data, we calculated the geometric mean as a 3-year running average (i.e., year t, t-1, and t+1).

We refer to total return as the annual number of adult Coho Salmon arriving in coastal marine areas on their return to freshwater prior to interception by fisheries (i.e. catch plus escapement). We estimated total returns for Interior Fraser Coho from estimates of total escapement of wild fish and exploitation rate, where total return = wild escapement / (1-exploitation rate).

For a semelparous Pacific Salmon species such as Coho Salmon, productivity is generally referred to as the number of pre-fishery adult recruits per brood spawner, and represents a measure of survival across the life cycle of an individual cohort. We estimated intergenerational productivity as $\ln(R_t/S_{t-3})$, where R_t is recruitment (i.e. total return) in year t, and S_{t-3} is the abundance of parent spawners (i.e. escapement) three years previous. Negative productivity estimates represent negative population growth (i.e., < 1 recruit per spawner), when a population is unable to replace itself, even in the absence of fishing. Population growth can only occur when post-fishing spawner recruits per spawner (S_t/S_{t-3}) exceeds one.

To estimate productivity for wild Interior Fraser Coho it is necessary to include hatchery-origin Coho Salmon that spawn naturally in streams (see previous section) as part of brood spawner escapement (S_{t-3}) because their progeny are indistinguishable from wild adult Coho Salmon. Coho salmon (wild and hatchery-origin) that are spawned in hatcheries are not included in estimates of brood escapement. Recruitment (R_t) is based on escapement estimates for wild adults only (see previous section), which include recruits from both wild-origin parents and hatchery-origin parents that spawned in natural habitat. Our estimates of productivity are biased high to a modest degree as a result of unmarked first generation hatchery fish straying to unenhanced streams, and being included in escapement estimates for wild fish (see previous section). Our estimates of total return and productivity are also fairly uncertain for 1975-1985 because both these parameters depend on estimates of exploitation rate, and there are no year-specific estimates of exploitation rate for this period (the mean value for a 1986-1997 base period is used to estimate exploitation rate for all years during 1975-1985; see *Section 3.1*).

2.1.4. Rate of Change in Abundance

We examined the rate of change in escapement of Interior Fraser Coho (for individual CUs and for the aggregate as a whole) for the most recent one (2010-2012[3]), three (2004-2012), and five generations (1998-2012) of Coho Salmon that have returned to the Interior Fraser since the implementation of the recovery program in 1998. For each time span, we estimated rate of change using a linear time-trend model (linear regression of escapement against year). Time-trend models were fit to $\log_e$-transformed escapement data (smoothed using the 3-year running geometric mean) to remove the annual "noise" in abundance that can obscure underlying trends (Grant et al. 2011). We used the coefficient value for the slope of the regression to estimate the annual intrinsic rates of change in the population (r_a). The finite rate of change per year is $1-e^{r_a}$ and the proportional change over *n* years is $1-e^{nr_a}$ (Bradford 1998).

2.1.5. Distribution

There are a number of different metrics available to assess spatial distribution and trends in distribution for Pacific salmon (Holt et al. 2009; Peacock and Holt 2010, 2012), but most of these require time series of geographic data describing distribution of spawners or juveniles, and these data are not available for Interior Fraser Coho. However, the number of occupied spawning locations, which is probably the most frequently used metric to assess distribution of Pacific Salmon, can be assessed (with some limitations) for Interior Fraser Coho based on annual spawner survey data for individual streams. We defined a unique spawning location as an individual stream where live spawners or carcasses were detected. Recent reviews of appropriate metrics of distribution for Pacific Salmon have also treated individual streams as locations (Holt et al. 2009; Peacock and Holt 2010, 2012; de Mestral Bezanson et al. 2012).

As a first step in assessing distribution status of Interior Fraser Coho, we examined the potential relationship between distribution and abundance. Empirical studies suggest that the proportion of occupied spawning locations typically increases exponentially with spawner abundance until a maximum (asymptotic) occupancy is reached (Peacock and Holt 2010). Thus, the relationship between distribution and abundance may be an important factor in determining appropriate escapements objectives for Interior Fraser Coho.

Comparing the number of spawning locations occupied by Interior Fraser Coho among years and at different escapement levels is problematic because survey effort (i.e., number of streams surveyed each year) has been inconsistent among years, with the most notable example being the expansion of the escapement monitoring program beginning in 1998. Moreover, the escapement monitoring program for Interior Fraser Coho was designed to detect trends in population size rather than distribution (Peacock and Holt 2010, 2012), and survey effort, particularly in years prior to 1998, was focused on relatively productive streams that contributed significantly to overall escapement (i.e., streams were not selected at random). To address

[3] *n*+1 years of data are required to estimate the rate of change for a period of *n* years (COSEWIC 2010). For example, 2009-2012 data are required to estimate r_a for the 2010-2012 generation of Interior Fraser Salmon.

variation in survey effort among years we included both escapement and the number of streams surveyed (N_{survey}) in regression models[4] that predicted the number of streams where Coho Salmon were detected (N_{detect}), or we substituted the proportion of surveyed streams where Coho Salmon were detected (P_{detect}) for N_{detect}. We also modelled the distribution-abundance relationship separately for the pre- and post-1998 periods. Where possible these analyses were done at the CU level as well as at the aggregate level. It is important to note that the true number of streams with Coho Salmon present and the true proportion of surveyed streams with Coho salmon present will be greater than N_{detect} and P_{detect}, respectively, because not all streams are surveyed, and detection probability in surveyed streams is less than 100% (English et al. 1992).

To describe the distribution status for the most recent generation of Interior Fraser Coho, we summarized the cumulative number (and proportion) of unique streams where spawners were detected during 2010-2012 for both the aggregate and for individual CU. Where possible we compared recent distribution to that during previous periods and at different escapement levels, and discussed the limitations of these comparisons.

2.1.6. IFCRT's Abundance-Based Recovery Objectives

We assessed Interior Fraser Coho escapements (aggregate) against two abundance-based recovery objectives proposed by the IFCRT (2006): their 'short-term" objective #1', which consists of maintaining >1,000 naturally spawning wild Coho Salmon (3-year geometric mean) in at least half of the subpopulations they proposed within the five CUs; and their 'long-term' objective #1', which consists of maintaining >1,000 wild spawners (3-year geometric mean) in all 11 subpopulations. As a first step, we reapplied the IFCRT's original analysis to a longer time series of escapement data (1975-2012) to determine the aggregate escapement needed, on average, to meet each objective. We smoothed the escapement time series for each subpopulation by calculating 3-year running geometric means, and tabulated the number of subpopulations with escapements of <1,000 individuals ($Count_{SUB}$), and the number of CUs with less than 1,000 spawners in more than one half of their subpopulations each year ($Count_{CU}$). We then plotted the inverse relationships between $Count_{SUB}$ and $Count_{CU}$ and aggregate escapement (3-year geometric running mean). We also used logistic regression to estimate the probability of meeting each of the two recovery objectives. The response variable is whether or not the recovery objective is met (i.e., $Count_{SUB} \geq 0$ or $Count_{CU} \geq 0$), and the predictor variable of interest is aggregate escapement. The probability of meeting the short-term recovery objective as a function of aggregate escapement is:

$$\mathrm{P}(\mathrm{Count}_{CU} \geq 0) = \frac{1}{1 + e^{-(\beta 0 + \, \beta 1 \mathrm{Esc})}}$$

where β_0 and β_1 are the constant and slope parameters, respectively.

2.2. RESULTS AND DISCUSSION

2.2.1. Recent Abundance and Abundance Trends

For the most recent generation (2010-2012), aggregate wild Coho Salmon escapement to the Interior Fraser River watershed averaged 36,000 adults (geometric mean, Table 4), or an estimated 38,000 adults if hatchery-origin fish are included[5]. These values are about 60% lower than escapements during 1975-1988 when the population experienced a period of relatively

[4] Data were natural log-transformed prior to analysis.

[5] See *Section 2.1.2* for definitions of hatchery- and wild- origin fish.

high and stable escapement (~60,000, Table 2, Figure 3), 2.5-fold lower than peak observed escapement in 1984 (91,000), and 4- to 5-fold higher than the lowest observed escapements in 1996 (9,000[6]) and 2006 (7,000), respectively. Although escapements have been quite variable since the implementation of conservation measures in 1997-1998, (Figure 3a), a smoothed trendline (3-year running geometric mean, Figure 3b) shows a 2.5-fold increase in escapement from 1997 to 2002, followed by a comparable decline from 2002 to 2005, and then another 2.5-fold increase from 2005 to 2012. Final escapement data for 2013 were not available for inclusion in this document. However, preliminary results suggest a total escapement of ~55,000 wild spawners for the Interior Fraser Coho aggregate (L. Ritchie, Fisheries & Oceans Canada, Kamloops, BC, personal communication, 2013), which would result in a geometric mean of 42,000 adults for the 2011-2013 generation.

With respect to total return of wild-origin Coho Salmon to the Interior Fraser watershed, the geometric mean for the most recent generation (41,000 adults for 2010-2012, Table 2) was 4-fold lower than the mean for 1975-1988 (181,000 adults). The decline in escapement over time was much less than the decline in total return because fisheries exploitation rates were much lower after 1998 (Table 2), and this reduced exploitation offset the large decline in productivity that occurred (see *Sections 3.2.2* and *2.2.2*). Since 1998, most returning Interior Fraser Coho have been allowed to escape to the spawning grounds (Figure 3).

Coho Salmon escapements to the North and South Thompson CUs followed a similar trend to that described above for the Interior Fraser aggregate (Table 2, Figure 4). The Lower Thompson CU also declined in abundance during the 1990s, but to a lesser degree. By contrast, escapements to the Middle/Upper Fraser CU have remained stable during the relatively recent period when monitoring has occurred (1998-2012), with no strong positive or negative trend. Escapements to the Fraser Canyon CU declined about 5-fold during 1998-2007, and then increased about 3-fold during 2007-2012. For the 1998-2012 period, when all five CUs were surveyed consistently, annual escapements to the South and North Thompson CUs were more variable compared to those for the other CUs (Figure 4). For the most recent generation (2010-2012), mean escapements to individual CUs ranged from 2,800 for the Fraser Canyon CU (Table 4), to 11,600 adults for the North Thompson CU. Owing to the relatively large escapement in 2012, these values, along with the total value for the aggregate, are 30%-50% higher than equivalent values reported for 2009-2011 by Decker and Irvine (2013).

For the most recent generation, the proportion of hatchery-origin Coho Salmon naturally spawning in Interior Fraser streams was low, ranging from 0%-9.2% among the five CUs, and amounting to an estimate 5.2% for the Interior Fraser Coho aggregate (Table 4). This represents a decline from previous years (Figure 3) when hatchery production in the Interior Fraser watershed was considerably higher (Decker and Irvine 2013).

2.2.2. Productivity

A time series plot of productivity (ln(recruits/spawners)) for Interior Fraser Coho suggests a period of decline from 1978-2005 (adult recruits), followed by a period of highly variable, but generally increasing productivity during 2005-2012 (Figure 5a)[7,8]. This trend roughly

[6] Escapement survey methods were generally less intensive and accurate prior to 1998 (see *Section 2.1.1*).

[7] Annual recruits/spawner data are provided in Table 2.

[8] Productivity estimates for 1978-1985 are less certain because productivity estimates depend on exploitation rate estimates (see *Section 2.1.3*), and there are no year-specific estimates of exploitation rate for this period (the mean ER value for 1986-1997 base period is used to estimate ER for all years during 1975-1985; see *Section 3.1*).

corresponds to a trend of predominately positive (warm) and negative (cold) values for the Pacific Decadal Oscillation (PDO) climate index for the two respective periods. Similar observations have been frequently reported for Pacific Salmon (Mantua et al. 1997). We found that the trend in productivity over time is confounded by the inverse relationship between productivity and brood escapement (presumably the result of density-dependent freshwater survival). When variation in brood escapement is controlled for by plotting annual productivity against brood escapement (Figure 5b), two distinct periods of productivity emerge: 1978-1993 and 1994-2012 (1975-1990 and 1991-2009 brood years, respectively). These periods corresponded approximately to a 1989-1990 shift in marine conditions (Beamish and Bouillon 1993; Irvine and Fukuwaka 2011). Productivity was considerably lower during the later period (ANCOVA, n=35, df=1, F-$stat$=66.2, P<0.000001). A similar contrast between the two periods is apparent in annual smolt-adult survival estimates for Strait of Georgia wild Coho Salmon indicator stocks[9] (Figure 6). The positive correlation between Interior Fraser Coho productivity and Strait of Georgia Coho Salmon smolt-adult survival (R^2=0.35, Figure 6) suggests that the current low productivity regime for Interior Fraser Coho is primarily the results of reduced marine survival as opposed to freshwater survival or production. During the current low productivity period, there have been eight years when productivity was less than 0, meaning that Interior Fraser Coho were unable to replace themselves (Figure 5a).

A plot of observed exploitation rates versus observed recruits/spawner during 1986-2012[10] (Figure 7) illustrates that, prior to the introduction of the recovery program in 1998, exploitation rates were unsustainable (i.e., post-fishing recruits per spawner < 1.0) in every year except 1986 and 1988. If exploitation had been sufficiently reduced, the population would have replaced itself every year during this period with the exceptions of 1991, 1995, and 1997 (i.e., productivity > 0; Figure 5a). Figure 7 demonstrates that to maintain or build upon a given level of abundance, exploitation rates must be sensitive to productivity (i.e., exploitation must be sufficiently low to maintain post-fishing recruits per spawner at or to the right of the replacement line, respectively.

By contrast, during 1998-2012, when restrictions were imposed on the various fisheries sectors, overall exploitation was sufficiently low (4%-13%) to allow for positive population growth (i.e., post-fishing recruits/spawner > 1), in nine of 15 years (Figure 7). Fishing contributed to negative population growth in the six remaining years (2000, 2003-2006, 2010), but the population would not have replaced itself during these years even in the complete absence of exploitation (Figure 5a). Productivity has been greater than zero in five of the last six years (2 generations), with 2010 being the most recent return year that was below replacement (Figure 5a). In 2012 productivity was near the upper range of the data for the lower productivity period (1.03 or 2.8 recruits/spawner; Table 2, Figure 5b); preliminary escapement results suggest that recruits/spawner was ~1.6 for 2013, roughly half that for 2012 (Figure 5b). However, greater compensation at lower stock size (Figure 5b) could largely explain higher productivity in 2012 versus 2013.

2.2.3. Rate of Change in Abundance

Since a major shift to lower fisheries exploitation in 1998, aggregate escapements of wild adult Coho Salmon to the interior Fraser River have increased, on average, by an estimated 1.6% per year, or 26.1% over five generations (Table 5). Four of the individual CUs experienced increases in escapement during this period as well, with rates of increase ranging from 0.7% per year for the North Thompson CU (10.3% for the entire period, Table 5), to 7.6% per year for the

[9] See Decker and Irvine 2013, Section 11.5 for details.

[10] Year-specific exploitation rates are not available for years prior to 1986 (see *Section 3.1*).

Lower Thompson CU (200% for 1998-2012). In contrast, escapement to the Fraser Canyon CU declined 4.5% per year (-49.9% for 1998-2012), leaving this CU with the lowest escapement of the five CUs for the most recent generation (Table 4). Prior to computing estimates for the Fraser Canyon CU, we removed the low escapement value of 84 spawners in 2006 (Table 2) because it was negatively biased by the poor surveys conditions that occurred during all surveys of the Nahatlatch River (sole spawning stream) in that year (R. Bailey, Fisheries & Oceans Canada, Kamloops, BC, personal communication, 2013).

In most cases, annual rates of increase in escapement for each CU and for the Interior Fraser aggregate were incrementally higher over consecutively more recent time periods (i.e., 5, 3, and 1 generation(s), Table 5), meaning that, Interior Fraser Coho have experienced accelerating population growth during 1998-2012. Although the Fraser Canyon CU population experienced negative population growth over the past three and five generations, during the most recent generation (2010-2012), it had the highest rate of increase in escapement of the five CUs (37.5% per year versus 13.2%-29.5% per year for the other CUs).

We also examined the rate the change in total return (escapement + harvest) of Interior Fraser Coho at the CU and aggregate level. The results were essentially the same as those described above for escapement (due to very low exploitation rates from 1998 onward), and are not shown.

2.2.4. Distribution of Interior Fraser Coho

2.2.4.1. Relationship between distribution and escapement

The number of Interior Fraser streams surveyed each year (N_{survey}) was highly variable over the available time series. Survey effort was fairly constant during 1975-1993 (46-64 streams per year, Figure 8), then decreased to 37-45 streams per year in the mid-1990s, followed by an increase to 70-104 streams per year when the survey program was expanded in 1998.

For years prior to 1998, 96% of the variation in the absolute number of streams where Coho Salmon were detected (N_{detect}) can be explained simply by N_{survey} (regression, n=23, R^2=0.96, Figure 9a)[11]. Moreover, in the 1990s N_{survey} declined along with aggregate escapements (Figure 9b), as funding for assessments was reduced. A plot of N_{detect} versus escapement for pre-1998 data suggests a positive relationship (Figure 9c), but this is an artifact of the positive relationship between escapement and N_{survey}. When escapement was added as a second predictor variable to the regression model described above, it was not significant and did not explain additional variation in N_{detect} (Table 6). When variation in survey effort was controlled for by plotting the proportion of surveyed streams with Coho Salmon detected (P_{detect}) against escapement (as opposed to N_{detect} versus escapement), there was also little evidence of a relationship (Figure 9d). These results all indicate that there is insufficient information about distribution (i.e., number of streams or locations occupied by spawners) contained in the pre-1998 data to evaluate the relationship between distribution and escapement or to examine trend in distribution. During this earlier period, surveys were limited, for the most part, to the more productive streams that contained persistent spawning groups. Moreover, as the aggregate population declined in the 1990s, survey effort declined as surveys were discontinued in some streams where Coho Salmon were no longer commonly observed.

Survey data collected since the inception of the recovery program and a more intensive escapement monitoring program in 1998 are better suited for evaluating distribution of Interior Fraser Coho. During 1998-2012 a relatively large number of streams were surveyed each year regardless of escapement (Figures 8, 9b), and this expanded dataset contains a larger

[11] Data were natural log-transformed prior to analysis.

component of less productive streams with less persistent spawning groups as evidenced by lower P_{detect} values at similar escapement levels for the post-1998 time series compared to the pre-1998 series (Figure 9d). In the post-1998 time series, N_{detect} was a function of both escapement and N_{survey} (Figures 9b and 9c). Escapement alone explained 64% of the variation in N_{detect}; and an additional 25% of the variation in N_{detect} *was explained* N_{survey} when N_{survey} was added to the model (R^2= 0.89, Table 6)[1].

The post-1998 data clearly indicates that the spatial distribution of Interior Fraser Coho is positively associated with overall abundance. The strong log-linear relationship between P_{detect} and escapement during 1998-2012 could be used to develop a distribution-based recovery objective/benchmark for Interior Fraser Coho. Ideally, additional years of data with higher aggregate escapements are needed (observed range during 1998-2012 was 7,000-56,000 spawners) in order to better determine escapement levels required for P_{detect} to approach a theoretical upper asymptote. Our analysis suggests that incremental gains in P_{detect} beyond ~85% stream occupancy are possible at aggregate escapements greater than the observed post-1998 peak returns of ~50,000-55,000 spawners (Figure 9d). If maximizing distribution is considered a priority as part of the recovery/conservation efforts for Interior Fraser Coho, it is clear that a higher escapement target would be needed than the targets required to meet two abundance-based recovery objectives proposed by the IFCRT (3-year geometric means of 20,000 and 40,000 spawners, see next section).

At the CU level, the results of our analysis were similar: N_{survey} and escapement were significant predictors of N_{detect}[12] for three of the four units (South and North Thompson, and Middle/Upper Fraser (Table 6, Figure 10) that contain multiple spawning locations[13] during 1998-2012. The exception was the Lower Thompson CU, where N_{detect} was not related to either predictor variable (Table 6, Figure 10). Of the four CUs, the Lower Thompson had the lowest number of streams surveyed (5-9 streams/year compared to 6-21 streams for the Middle/Upper Fraser, and 23-33 and 27-40 streams for the North and South Thompson CUs, respectively). Similar to that for the Interior Fraser aggregate, data for the South and North Thompson, and Middle/Upper Fraser CUs suggest a log-linear relationship between P_{survey} and N_{detect} (Figure 10) that could be used to develop CU specific, distribution based recovery objectives.

2.2.4.2. Recent distribution

During 2010-2012 (most recent generation), a cumulative total of 99 Interior Fraser streams were surveyed (not all 99 streams were surveyed each year), and live Coho Salmon or carcasses were detected in a cumulative total of 87 (88%) of these streams. This represents peak distribution for the Interior Fraser aggregate for the post-1998 recovery period (Figure 8, see previous section). However, because 2010-2012 escapements were low relative to those during the 1970s and 1980s, and distribution is strongly positively associated with escapement (Figures 9c, 9d; see previous section), it is likely that Coho Salmon were more broadly distributed in the Interior Fraser during this earlier period, but this cannot be verified due to lower survey effort at that time.

For the South, North, and Lower Thompson and the Middle/Upper Fraser CUs, Coho Salmon were detected in 32, 32, 8, and 14 streams, respectively, during 2010-2012 (cumulative total over 3 years). However, it should be stressed that the total number of streams in each CU that were occupied by the most recent generation of Coho Salmon is underestimated in our data because not all streams where Coho Salmon spawn are surveyed (R. Bailey, Fisheries & Oceans Canada, Kamloops, BC, personal communication, 2013), and because detection

[12] Data were natural log-transformed prior to analysis.

[13] The Fraser Canyon CU is represented by a single spawning location (Nahatlatch River).

probability in surveyed streams is less than 100%. Incomplete survey coverage is particularly relevant in the case of the Middle/Upper Fraser CU. During 2010-2012, surveys in this CU were limited to the Bridge River and the Seton River watershed (including tributaries) in the Middle Fraser, and the Chilcotin River and the Quesnel River watershed in the Upper Fraser. However, within this CU, historical records indicate that Coho Salmon have spawned at least as far upstream as the Nechako River system, and in other middle and upper Fraser tributaries that were not surveyed in 2010-2012 (e.g., West Road/Blackwater River). Based on common landscape and geomorphologic attributes, there would appear to be an extensive amount of suitable habitat available for Coho Salmon within the Middle/Upper Fraser CU. Much of this potential habitat has limited road access, and occurs in localized patches within very large drainages. The high cost of the extensive surveys that would be required to adequately assess spawner numbers has limited recent efforts to better define current Coho Salmon distributions in the Middle/Upper Fraser CU (R. Bailey, Fisheries & Oceans Canada, Kamloops, BC, personal communication, 2013). Survey coverage is more comprehensive in the South, North, and Lower Thompson CUs. However, in recent years survey coverage has been discontinued in a number of Shuswap Lake and the lower Shuswap River tributaries within the South Thompson CU where Coho have historically been observed[14]. Coho Salmon were detected in eight streams in the Lower Thompson CU during 2010-2012, but were likely present in 10 or more streams, as several streams in the Nicola River system that likely contained spawning Coho were not surveyed (R. Bailey, Fisheries & Oceans Canada, Kamloops, BC, personal communication, 2013).

2.2.5. Abundance of Interior Fraser Coho in Relation to IFCRT Objectives

The IFCRT proposed a short-term recovery objective of maintaining a minimum of 1,000 naturally spawning wild Coho Salmon (3-year geometric mean) in at least half of the subpopulations for each of the five CUs (i.e., short-term objective #1). We found, based on empirical data for 1975-2012, that this objective was never achieved at aggregate escapement levels up to 18,000 spawners, and was always achieved at average escapements of 19,000 and higher (Figure 11a). Correspondingly, logistic regression predicted a very sharp threshold in the probability of meeting the short-term objective, from near 0% at an aggregate escapement of 18,000, to near 100% at an escapement of 20,000 spawners (Figure 12a). Our results were similar to the results of the original analysis conducted by the IFCRT (1975-2003 data) that suggested that aggregate escapements of 20,000-25,000 spawners were required to meet this short-term objective.

Prior to assessing the number of spawners required to meet the IFCRT's long-term recovery objective #1 (maintaining a minimum of 1,000 naturally spawning wild Coho Salmon (3-year geometric mean) in all of the subpopulations), we removed the Lower Thompson subpopulation from the analysis. Unlike the other 10 subpopulations, the trend in escapement for the Lower Thompson subpopulation showed little correlation (R=0.16) with that for the Interior Fraser Coho aggregate, and the Lower Thompson subpopulation was the only subpopulation that had 3-year mean escapements less than 1,000 spawners when aggregate escapement (3-year mean) exceeded 40,000 spawners (Figure 11b). Conversely, in some years, the Lower Thompson subpopulation had 3-year mean escapements greater than 1,000 spawners when aggregate escapements to the Interior Fraser were as low as 14,000 spawners. Data quality is likely an issue in the case of the Lower Thompson subpopulation; escapement estimates for 1975-1983 are extrapolated based on a proportional relationship with escapements for the North and South Thompson CUs during 1998-2000 (see *Section* 2.1.1), and problems with monitoring programs

[14] Several of these streams were surveyed in 2013 (B. Whitehead, Fisheries & Oceans Canada, Kamloops, BC, personal communication, 2013)

during 1984-2012 have been noted (R. Bailey, Fisheries & Oceans Canada, Kamloops, BC, personal communication, 2013).

In an analysis of the remaining 10 subpopulations, we found that the IFCRT long-term objective was met at aggregate escapements as low as 26,000 spawners in some years, and was not met at escapements as high as 33,000 in others (Figure 11b). Logistic regression predicted that the probability of meeting the long-term objective increased from near 0% at an aggregate escapement of 18,000, to 50% at 31,000 spawners, to 98% at 40,000 spawners (Figure 12b). Based on these analyses, we assumed that escapement levels of 20,000 and 40,000 spawners (3-year running geometric mean) would result in near 100% probability that the IFCRT's short-term objective #1 and long-term objective #1 would be met, respectively.

Since the inception of the recovery program in 1998, aggregate escapements (3-year running geometric mean) have failed to meet the short-term objective (20,000 spawners) in five of 15 years (1998, 1999, 2005-2007; Figure 13). However, since 2008, the short-term objective has been met in every year including 2013 (based on a preliminary estimate of 55,000 spawner in 2013, see Section 2.2.1). The long-term objective (40,000 spawners) was not in any year during 1998-2011 (it was last met in 1990; Figure 13). However, when the preliminary escapement estimate for 2013 is included in the time series, the 3-year running means for 2012 and 2013 (42,000 and 55,000 spawners, respectively) both exceeded the long-term objective. If the subpopulations are considered individually, there is considerable variability among them with respect to how consistently the objective of 1,000 spawners (3-year running geometric mean) was met during 1998-2012. For example, the Adams River and Lower Thompson subpopulations met the 1,000 spawner objective in only 33% and 67% of the years, respectively, while the Middle/Lower Shuswap, Shuswap Lake, and Middle and Lower North Thompson subpopulations met the objective every year (Table 4).

3. EXPLOITATION RATE

3.1. ESTIMATION METHODS

Methods used to estimate fishery exploitation (catch/(catch + escapement)) for the Interior Fraser Coho aggregate (data are not available to estimate exploitation rate for individual CUs) have varied during the time series. From the introduction of hatchery supplementation in 1986 until 1997, exploitation rates and marine distribution for Interior Fraser Coho were estimated using mark recovery data obtained through the Mark Recovery Program operated by Fisheries and Oceans Canada (Simpson et al. 2004). Recoveries of CWT marked Coho Salmon from Canadian marine and in-river fisheries and US marine fisheries, together with estimates of total escapement, were used to estimate exploitation rate and apparent marine distributions and survival (Johnson 1990 provides a detailed summary of Canadian and US coded wire tagging programs). As was done in previous assessments (e.g., Simpson et al. 2004), we assumed a constant exploitation rate of 68% for Interior Fraser Coho (Table 2) 1975-1985 based on the arithmetic average of escapement estimates for 1986-1996 that were derived from CWT recoveries

From 1998-onward, reduced Coho Salmon abundance, restrictions on retention of Coho Salmon in commercial and sport fisheries, and reductions or curtailments in CWT programs meant that exploitation rates could no longer be reliably estimated from the mark recovery data (Simpson et al. 2004; Irvine et al. 2013;, PSC-JTC 2013). During 1998-2000, genetic samples were collected from Coho Salmon in most fisheries annually, and Canadian (marine and in-river) and US exploitation rates on Interior Fraser Coho were derived by estimating the number of Coho Salmon encounters by catch area, and gear specific mortality rates for fisheries occurring in those areas, and then applying estimates of the proportion of Interior Fraser Coho in those encounters based on genetic stock identification (Irvine et al. 2001; Simpson et al. 2004).

For 2001-2012, Canadian marine exploitation rates on Interior Fraser Coho were estimated using a model that scaled average exploitation rate from a baseline period (1987-1997; when exploitation rates could be reliably estimated from CWT recoveries) by the amount of fishing effort each year relative to average effort for the baseline period (Simpson et al. 2004). Similarly, United States (including Alaskan) exploitation rates on Interior Fraser Coho were estimated using their Fisheries Regulation Assessment Model (FRAM; MEW 2008), which relies on exploitation rates derived from CWT recoveries from US origin marine fisheries during an earlier based period that are scaled to reflect fishing effort in the current year relative to the baseline period. To estimate Canadian in-river (lower Fraser River) exploitation rates, total daily Coho Salmon mortalities are estimated for each fishery component as the sum of Coho Salmon taken plus the product of the number of encounters and the associated gear specific mortality rates, and this value is multiplied by the modelled proportion of Interior Fraser Coho present in the daily catch (Simpson et al. 2004). Modelled declines over time in the proportion of Interior Fraser Coho present in the daily catch ('decay model') and the parameters of this decay are derived from an empirical fit of a Bayes model to DNA samples collected during 1997-1999 (Irvine et al. 2000; Simpson et al. 2004). The models described above all assume stationarity in spatial stock distributions, but vary in the coverage of individual fisheries, and the incorporation of release mortality and natural mortality rates. For example, the Canadian marine and Fraser River decay models assume release mortality only, while the US FRAM model assumes both release and natural mortality. Neither model considers drop-off mortality. Domestic exploitation rate estimates for Interior Fraser Coho for 1975-2003 are summarized in Simpson et al. (2004). Exploitation rates for 1986-2009 are summarized by the PSC Joint Coho Technical Committee (PSC-JCohoTC 2013). Exploitation rates reported in this document for 2010-2012 were provided by DFO Science Branch. The FRAM model has been reviewed by Coho Salmon experts on the PSC Coho Technical Committee, but it has not undergone a formal peer review process such as a journal publication. These data are the best estimates available, and have been used to make inferences about fishing impacts on Interior Fraser Coho in recent CSAP assessments (Decker and Irvine 2013; Irvine et al. 2001; Simpson et al. 2004; Folkes et al. 2005).

3.2. RESULTS AND UNCERTAINITY

Modelled estimates of Canada and US combined exploitation rates averaged 10% during 1998-2012 (range: 4%-14%, Table 2, Figure 5a). Since 2003, annual estimates of exploitation have varied even less, ranging from 9%-13%. From 1986-1997, average exploitation was nearly seven fold higher (mean: 66%, range: 41%-88%) compared to the current recovery period (1998-2012). It has been suggested that the pre-1998 period of high exploitation rates for Interior Fraser Coho may have extended as far back as the early 1900s given the near-shore ocean distribution of Coho Salmon and the large number of fisheries in these waters historically (IFCRT 2006). Unsustainable fishing occurred in the late 1980s and 1990s as exploitation rates actually increased when they ought to have been reduced in response to climate-driven reductions in productivity. Since 1998, fishery exploitation has had relatively little impact on escapements of Interior Fraser Coho as evidenced by the nearly overlapping trend lines for total return and escapement in Figure 3. Given the mitigating effect of reduced exploitation after 1998 (Figure 5a), the trend in total returns (Figure 3) reflects the decline in productivity of Interior Fraser Coho that occurred during 1978-2005 (Figure 5a) more accurately than does the trend in escapement.

The modelled exploitation rates are likely underestimated due to unreported catch and releases (Table 3). Terminal harvest is not included in the in-river model. Recorded numbers of fish released in mark-selective fisheries (recall bias) are known to be biased low and have not been corrected for under-reporting (Diewert et al. 2005). In the South Coast recreational fishery, catch is assumed to be zero in areas and at times that are not sampled by a creel survey. Thus, bias in estimates of catch likely increased, as creel survey coverage was reduced over time since the base period.

The reliability of exploitation rate estimates for Interior Fraser Coho from 1998 onward is uncertain for several reasons. First, the estimation models assume stationarity through time in the spatial distribution and migration timing of Interior Fraser Coho and other Coho Salmon populations through the various fisheries. This assumption is highly uncertain given observed year-to-year shifts in the distribution of Coho Salmon between the Strait of Georgia and the west coast of Vancouver Island in the 1990s, and the difficultly in inferring inside-outside distribution changes in more recent years in the absence of directed fisheries on Coho Salmon. The Canadian marine exploitation and US FRAM models depend on comparisons of fishing effort in recent years versus the baseline period, but how similar current fisheries are compared to the baseline period is questionable given that during the baseline period directed fisheries on Coho Salmon occurred, whereas in recent years Coho Salmon were mainly intercepted as by-catch in fisheries targeting other species. For example since 2008, the West Coast Vancouver Island (WCVI) troll fishery has been restricted to larger gear (i.e., ‘6 inch’ plugs) during July and August to reduce encounters with Coho Salmon, and many recreational anglers actively try to reduce encounters with Coho Salmon due their awareness of the population’s conservation status. The absence of significant directed fisheries on Coho Salmon in recent years has also meant that monitoring of fishing effort on Coho Salmon has declined, which has led to increased uncertainty in estimates of fishing effort (all models), and encounter rates and gear specific mortality rates in the case of the Fraser in-river decay model (Simpson et al. 2004; PSC-JCohoTC 2013). Finally, estimates of release mortality for Coho Salmon in commercial and recreational fisheries are based on data from a limited number of studies, and are also highly uncertain (PSC-JCohoTC 2013).

The largest uncertainty in the exploitation rate estimates is due to the assumption that base period effort and exploitation rate (16-26 years ago for FRAM) is representative of current effort and exploitation rate. This base period-to-present day relationship is difficult to assess and is beyond the scope of this assessment. There have also been several shifts in the spatial-temporal distribution of fishing effort in the WCVI fishery due to restrictions protecting WCVI-origin Chinook Salmon. Since 1996, many of the WCVI inlets have become non-retention or closed areas for Chinook Salmon, and this has shifted recreational fishing effort to inside areas with more abundant hatchery Chinook Salmon or to outside areas. These fine scale changes in recreational effort distribution are not represented in the assessment models. Another change in recreational fishing effort is the increasing popularity of fishing for Pacific Halibut (*Hippolglossus stenolepis*) since the base period, which has also contributed to a shift in fishing effort distribution to WCVI offshore areas. Recently, the South Coast Area creel survey has collected information about the target species. However this information is not available back to the base period. A possible solution is to collect sufficient data to directly measure fishing impacts. This requires an increase in the number of CWT’s applied to Interior Fraser Coho (or a suitable surrogate) and an increase the number of tags recovered from fisheries and escapements surveys. This would provide empirical rather than modelled exploitation rates.

Monitoring of Coho Salmon incidental mortalities, combined with genetic analysis of a subsample of the Coho Salmon in the net and troll fisheries, could provide exploitation rates estimates for Interior Fraser Coho that could be used to corroborate the current models. In the absence of this, management should be aware of the uncertainty and bias in the modelled exploitation rates, and should account for this in their management plans. Because our assessment of harvest impacts on Interior Fraser Coho (see next section) is based on biased exploitation rate estimates, the predicted response of the population to different exploitation rates under different productivity regimes will also be biased with respect to absolute values, but not necessarily with respect to the magnitude of differences among alternate harvest strategies. This is an important consideration if the current methods used to estimate exploitation rates for Interior Fraser Coho are modified, or if current fishing restrictions to protect Interior Fraser Coho are relaxed and this results in unanticipated or undetected changes in fishing effort, fishing methods, distribution of the fishery, etc.

4. EVALUATION OF POTENTIAL MANAGEMENT SCENARIOS

4.1. METHODS

4.1.1. Stock-Recruitment Analysis

Since the 1950s, salmon management has been largely driven by stock-recruitment analysis. Stock-recruitment analysis is dependent upon a history of observations of spawners and recruits (i.e., total escapement and total returns, Table 1). For Interior Fraser Coho, analysis of these data can provide an assessment of the mean relationship between spawners and resulting recruits. Many years of data are needed to assess mean stock-recruitment relationships; short time series can lead to severely biased estimates of maximum productivity and maximum stock size.

4.1.2. Stock Assessment and Model Selection

We undertook a model selection analysis to determine the most appropriate stock-recruitment model to be used to form the basis of harvest impact projections. In addition to evaluating the Ricker stock recruitment relationship (Hilborn and Walters 1992), we also evaluated the Hockey Stick model (Barrowman and Myers 2000, Bradford et al. 2000.) and the Beverton-Holt model (Hilborn and Walters 1992). We undertook the comparison of different models because many studies indicate that these latter models could, in some cases, more accurately reflect the biological drivers of recruitment for Coho Salmon stocks.

4.1.3. The Use of the Time Series Data Given Evidence of a Regime Shift

We evaluated the time series of spawners and recruits (i.e., escapement data) for Interior Fraser Coho using the three stock recruitment models. There was strong evidence of a sustained change in productivity for 1994-2012 (return years) versus 1978-1993 for the Interior Fraser aggregate resembling a regime shift. This shift in productivity is described in Section 2 of this report and is clearly evident in plots of recruits and recruits/spawner versus spawners (Figure 14). To address this regime shift, we evaluated the production models for harvest impacts analysis in terms of both the full time series (return years 1978-2012) and the recent portion of the time series corresponding to the period of reduced productivity (return years 1994-2012).

4.1.4. Application of Stock-Recruitment Models to the Time Series

We fit three stock recruitment models to the aggregate Interior Fraser Coho wild escapement time series. We did these analyses using data for both the full time series (1975-2012) and the recent period of lower productivity (1994-2012).

4.1.4.3. Hockey Stick model

The first model we fit was the Hockey Stick model of the form:

$$R_t = alpha * \min(S *, S_{(t-3)})$$

where *R* is the number of recruits and *S* is the number of spawners, alpha is the slope of a line between S* and the origin, and recruitment is assumed to vary log-normally around this mean relationship.

Use of the Hockey Stick model is suggested for populations where behavior of stocks at low stock size does not show the density dependent compensation assumed by other stock recruit models. Barrowman and Meyers (2000) warn that because of the discontinuous nature of the Hockey Stick function, care must be taken when fitting the model to avoid flat ridges or local maxima on the likelihood surface. In order to fit the Hockey Stick model they advocate a grid search. To fit the Hockey Stick model to the Interior Fraser Coho time series we implemented a Markov chain Monte Carlo (MCMC) procedure in the Stan programming language (Stan Development Team 2013), and used this to estimate posterior probability distributions for alpha, S* and the standard deviation of the model in log space. To avoid the problems of local maxima and flat likelihood surfaces, we used 10 chains started at widely chosen values. The ten chains all converged to the same posteriors values for the parameters over many implementations of the Stan model. To confirm the posterior estimates were reasonable, we mapped the negative log likelihood surface over a range of alpha and S* values.

4.1.4.4. Beverton-Holt model

The Beverton-Holt model we used to fit the Interior Fraser Coho time series took the form:

$$R_t = a * S_{(t-3)}/(b + S_{(t-3)})$$

where *a* is the maximum number of recruits produced, *b* is the number of spawners needed to produce half that number of recruits, and recruitment is assumed to vary log-normally around this mean relationship (Hilborn and Walters 1994). Hilborn and Walters suggest using a non-linear search to fit the relationship:

$$ln(R_t) = ln(a * S_{(t-3)}/(b + S_{(t-3)})$$

Similar to the Hockey Stick model, we used an MCMC procedure to estimate posterior probability distributions for the *a* and *b* parameters, and the standard deviation of the model in log space. We verified the posterior estimates by mapping the negative log likelihood surface over a range of *a* and *b* values.

4.1.4.5. Ricker model

We evaluated a Ricker stock recruitment model of the form:

$$R_t = S_{(t-3)} * e^{(a - b * S_{(t-3)})}$$

For this model *a* is related to maximum productivity of the stock and *b* can be used to estimate maximum recruits produced, and recruitment is assumed to vary log-normally around this mean relationship. We fit the linear relationship:

$$ln\left(\frac{R_t}{S_{(t-3)}}\right) = a - b * S_{(t-3)}$$

to the time series data using the same MCMC procedure we used for the other two models. We estimated the posterior distributions of the *a* and *b* parameters, and the standard deviation of the model in log space.

4.1.4.6. Use of AIC for model selection

The Akaike Information Criterion (AIC) is often used to compare model fits to a set of data. The normal AIC equation takes the form:

$$AIC = -2 * \ln L(M|Y) + 2 * p$$

where -2*lnL*(M|Y) is two times the negative log likelihood of the model given the data parameter combinations and *p* is the number of parameters in the model. Since the models all assume normal error structure around the log of the recruitment, and they are all two parameter models, the AIC is relatively easy to compute and can be used to compare model fits to the data. To compare the different models we compute:

$$\Delta_i = AIC_c(M_i) - AIC_c(M_{best})$$

as the difference in AIC score between the best model fit and the model fit being evaluated. The model with the lowest AIC is considered to be the model that best fits the data. Models with values similar to the best model ($DAIC_c$ = 0-2) are considered to have strong support, while those with larger AIC_c values are considered to have moderate ($DAIC_c$ = 4-7) or essentially no support ($DAIC_c$ > 10).

4.1.4.7. Recruitment Variability

In all models we assumed that recruitment varied log-normally around the mean predicted by the modelled relationship, and, in each case, that the models predicted the mean of that deviation (Table 8). In addition, we examined the recruits/spawner time series and found it to have a lag one autocorrelation of 0.394. So we modelled recruitment deviates (w_t) as normal deviates with an autocorrelation of 0.394 as follows:

$$w_t = rho * w_{(t-1)} + \sqrt{1 - rho^2} * N(0, sigma)$$

where *rho* is the autocorrelation coefficient, and sigma is the recruitment standard deviation.

4.1.5. Harvest Impact Projections

In order to project the possible impacts of harvest the stock productivities calculated from the stock-recruitment analyses are needed. These provide the mean recruitment response to the escapement allowed by any particular harvest regime and some measure of variability around that mean (we will refer to the latter as recruitment standard deviation). In order to be able to estimate the impacts of harvest on the Interior Fraser Coho, for each modelled recruitment we estimated the standard deviation of the recruitment (Table 7).

4.1.5.8. Closed-loop simulations

We conducted closed-loop simulations (Figure 15; see Walters and Martell 2004) to evaluate the effect of different exploitation rates on Interior Fraser Coho. We used closed-loop simulations to explore the impacts of harvest given a hypothetical stock-recruitment relationship and to examine how different harvest strategies (exploitation rates) perform. We used the best fit models and associated recruitment standard deviation from the model selection analysis to examine the impacts of harvest. We used a recruitment model as the operating model to generate a “true” picture of the stock to which different harvest strategies (in this case exploitation rates) are applied.

The applied exploitation rates generate catch and escapement data that we then fed back into the operating model. We ran simulations for one, two, and three generations and calculated the probability of the population being below the short-term recovery objective (20,000 spawners) or being below the long-term recovery objective (40,000 spawners). The performance of different exploitation rates, given underlying assumptions about productivity (i.e., different sets of stock-recruitment parameters), can be judged once this cycle is completed. We ran the closed-loop analyses assuming that the current stock size was the starting point. We used the last three years of escapement data in Table 2 as the starting point for simulations and projections.

4.2. RESULTS

4.2.1. Stock-Recruitment Analysis and Model Selection

The AIC model selection criteria suggests that for the recent period of lower productivity (1994-2012) the model that best explains the data is the Ricker model with an *a* parameter value of 0.849 and a *b* parameter value of 2.16e-05. (Figures 16a and 16b show all models fit to the data; Figure 17 shows the best fit model and replacement line.) When considering the whole time series (1978-2012), the best model fit is the Hockey Stick model with an alpha value of 1.997 and an S* value of 63552. (Figures 18a, and 18b show all models fit to the data; Figure 19 shows the best fit model and replacement line.) The model parameter estimates are presented in Table 7 and the AIC calculation results are presented in Table 8. When we mapped the negative log likelihood surface and overlaid the posterior estimates of the stock recruit parameters estimates to compare to the maximum likelihood estimates (Figures 16c, 16d, 16e and Figures 18c, 18d, 18e), we found that the estimates converged properly and did not get stuck on locale maxima.

The parameter estimates produced for the Ricker and Beverton-Holt models were compared to equivalent parameter estimates reported for Coho Salmon in previous meta-analyses (Korman and Tompkins 2014; Walters et al. 2008) and found to be similar.

4.2.2. Harvest Impact Projections

4.2.2.1. Recruitment deviations and natural variability in the system

For the low productivity time period (1994-2012) the recruitment standard deviation was 0.54 for the Ricker model. For the full time period the recruitment deviation was 0.69 for the Hockey Stick model. These standard deviations are comparable to those observed in other pacific salmon studies; a recruitment standard deviation in the range of 0.3-0.8 is commonly observed across salmon data sets.

4.2.2.2. Closed-loop simulations

4.2.2.2.1 Low productivity regime

Closed-loop simulations based on parameter estimates derived from the Ricker model, and the assumption that the recent period of low productivity (1994-2012) will persist, suggest a trade-off between the probability of achieving the short-term conservation goal (3-year geometric mean of 20,000 spawners) and exploitation rates. Our analysis suggests the probability of meeting the long-term recovery objective (3-year geometric mean of 40,000 spawners) is low even in the absence of harvest. We ran these simulations using the estimated recruitment deviation value of 0.54 that was associated with the Ricker model fits to the recent low productivity regime (1994-2012). Table 9 and Figure 20 show the probabilities of achieving the recovery objectives at a range of possible exploitation rates given these modelling assumptions. In addition to the probabilities of achieving the two recovery objectives, we made stock projections over 15 years based on the same range of exploitation rates and the Ricker stock recruitment model chosen above, and found that escapements were relatively stable at levels between 20,000-40,000 spawners when exploitation rate remained below 30%, were stable at ~20,000 spawners at 30% exploitation, and declined below 20,000 spawners at exploitation rates higher than 30% (Figures 22 and 23).

4.2.2.2.2 *Full time series*

Closed-loop simulations based on parameter estimates derived from the Hockey Stick model, and the assumption that average conditions for the full time series (1978-2012) would be representative of productivity for Interior Fraser Coho in upcoming years suggest a less severe trade-off between the probability of achieving the short-term recovery objective (3-year geometric mean of 20,000 spawners) and exploitation rate (Table 10 and Figure 21). Our analysis shows that the probability of meeting the long-term recovery objective (3-year geometric mean of 40,000 spawners) is higher as the stock rebuilds, and once it has done so, the stock will remains high at a range of exploitation rates. We ran these simulations using the estimated recruitment deviation value of 0.69 that was associated with the Hockey Stock model fits to the full time series of data (1978-2012). Use of this time series is not recommended because it is relatively un-informative as there is an explicit regime shift (Section 2.2).

4.3. SUMMARY

The Interior Fraser Coho are in a low productivity regime. In this regime the best fit model was the Ricker model and it was used as the basis for evaluating harvest impacts. We evaluated the probability of meeting the recovery objectives set out in the recovery document using closed-loop simulation. Under the current low productivity regime, the probability of meeting the short-term recovery objective decreases as exploitation rates increase, while the probability of meeting the long-term recovery objective is low at all exploitation rates. Table 9 and Figure 20 show the probabilities of achieving each objective at a range of exploitation rates. Implementation error, variability in the ability to implement a change in exploitation is not captured in the closed-loop simulations. Therefore, the probabilities of achieving the two recovery objectives that we report likely overestimate the actual probabilities (i.e., they are overly optimistic) given that implementation error would have led to increased uncertainty and resulted in a wider probability distribution of outcomes had it been included in the simulations. We also examined the trajectory of the stock over 15 years in response to exploitation rates and found that the mean trend was one of persistent declines in stock abundance at exploitation rates exceeding 30%.

Given the current low productivity regime for Interior Fraser Coho, there appears to be limited potential for recovering the management unit to abundance levels higher than 20,000-40,000 spawners (Figures 17, 21a). However, it should be noted that the stock-recruitment relationship was highly variable, with a wide range of possible recruitment outcomes for any one year for a given stock (e.g., 20,000-60,000 recruits for a brood escapement of 40,000). Given current productivity, fisheries managers are faced with a trade-off between maximizing potential escapements to address conservation biology issues associated with relatively small populations (CUs) distributed over large geographic areas at low densities (i.e., Allee effects, maintaining population structure, etc.), and maximizing harvest opportunities for other stocks. Based on the recommendations of the Conservation Strategy document (IFCRT 2006), escapements below 20,000 spawners (3-year geometric mean) for the Interior Fraser Coho aggregate should be avoided. Our simulations suggest that an escapement target based on this threshold (i.e., the short-term recovery objective) could maximize harvest opportunities for other stocks while still maintaining Interior Fraser Coho at a relatively productive point along the current stock recruitment relationship (Figure 17). However, given the current lack of WSP benchmarks for individual Interior Fraser Coho CUs, the substantial challenges and uncertainty in achieving target exploitation rates for the Interior Fraser aggregate (see *Section 3.2*), uncertainty in the stock-recruitment relationship for the aggregate, and observed recruitment failures (recruits/spawner < 1) as recently as 2010 (Table 2), there are significant risks associated with an escapement objective of only 20,000 spawners that must be recognized. The

Conservation Strategy clearly identified 20,000 spawners as a short-term objective, and recommended higher targets to address long-term objectives.

5. CONCLUSIONS AND ADVICE

- Significant fishery management actions, including the curtailment of all non-terminal directed fisheries, non-retention of unmarked Coho Salmon, roving closures, and gear restrictions that were first introduced in 1998, and have largely remaining in place through 2013, have been effective in capping total exploitation at 13% compared to an average of 67% prior to 1998[15].
- The trend in escapement for the Interior Fraser Coho aggregate has been positive since the inception of the recovery program in 1998, particularly during the most recent two generations (6 years). In most cases, this was true for individual CUs as well. The most recent generational average escapement for the Interior Fraser Coho aggregate (42,000 wild spawners during 2011-2013) was the largest observed since the recovery program was initiated in 1998. Recent generational average escapements for individual CUs (2,800-11,600 wild spawners) also approached or exceeded maximum values for 1998-2012. This recovery trend is the result of sustained harvest restrictions since 1998, coupled with modest improvements in productivity in recent years. However, there is no evidence that we have moved above ‘low’ productivity regime that has persisted since 1994 (return year), and recent productivity is well below a regime of relatively high productivity observed during 1978-1993. The potential for population growth beyond current levels is uncertain and likely limited until such time as marine survival improves. With respect to both the number and proportion of surveyed streams where adult fish were detected, the distribution of Interior Fraser Coho has also exhibited a positive trend since 1998.
- Generational average escapements for the Interior Fraser Coho aggregate exceeded 20,000 wild adults in every year from 2008 onward, an escapement level that ensures a high probability of meeting short-term objective #1 in the original Conservation Strategy (IFCRT 2006)[16]. Generational average escapements for the Interior Fraser Coho aggregate exceeded 40,000 wild adults in only the two most recent return years (2012 and 2013), an escapement level that results in a high probability of meeting long-term objective #1 in the Conservation Strategy[17]. The IFCRT did not recommend specific metrics or objectives for productivity or distribution. However, they recognized that any management actions that could be taken to maximize both productivity and distribution were important to the recovery and long-term sustainability of Interior Fraser Coho. Our assessment indicates that productivity (i.e., primarily marine survival) will need to improve substantially if Interior Fraser Coho are to recover to abundance levels observed in the 1970s and 1980s. Our results also suggest that aggregate escapements greater than those observed in recent years, and greater than the long-term objective of 40,000 wild adults, are needed to maximize spawner distribution in the Interior Fraser watershed.

[15] See Appendix A for a summary of these management actions.

[16] Maintain a minimum of 1,000 naturally spawning wild Coho Salmon (3-year geometric mean) in at least half of the subpopulations within each of the five Interior Fraser Coho CUs.

[17] Maintain a minimum of 1,000 naturally spawning wild Coho Salmon (3-year geometric mean) in all 11 subpopulations within the Interior Fraser Coho management unit.

- Exploitation rate estimates for 1998-2012 are highly uncertain and likely biased low. Our closed-loop simulations of harvest impacts on Interior Fraser Coho are based on an empirical stock-recruitment relationship derived in part from these estimates with the assumption that they are accurate. Correspondingly, the predicted response of the population to different exploitation rates under different productivity regimes will also be biased with respect to absolute values, but not with respect to the magnitude of differences among alternate exploitation rates. However, if the current methods used to estimate exploitation rates for Interior Fraser Coho are modified, or if current fishing restrictions to protect Interior Fraser Coho are relaxed and this results in unanticipated or undetected changes in fishing effort, fishing methods, distribution of the fishery, etc., the risk assessment provided here may not be applicable.
- For a productivity regime similar to the 1994-2012 period (low productivity), there is a strong trade-off between the probability of achieving the short-term objective of 20,000 wild spawners (3-year geometric mean) and exploitation rate. The probability of meeting the long-term objective of 40,000 spawners at low productivity is low regardless of exploitation rate. Population decline below 20,000 spawners was predicted at exploitation rates exceeding 30%. Assuming a continuation of the 1994 to 2012 low productivity regime for Interior Fraser Coho, there appears to be limited potential for recovering the management unit to abundance levels higher than 20,000-40,000 spawners. However, it should be noted that the stock-recruitment relationship was highly variable, with a wide range of possible recruitment outcomes for any one year for a given stock (e.g., 20,000-60,000 recruits for a brood escapement of 40,000). Given current productivity, fisheries managers are faced with a trade-off between maximizing potential escapements of Interior Fraser Coho (i.e., 3-year geometric mean escapements approaching 40,000 spawners with no exploitation) to address conservation biology issues associated with relatively small populations (CUs) distributed over large geographic areas at low densities (i.e., Allee effects, maintaining population structure, etc.), and maximizing harvest opportunities for other stocks. A relatively low escapement target within this range (20,000 spawners) could maximize harvest opportunities for other stocks while still maintaining Interior Fraser Coho at a relatively productive point along the current stock recruitment relationship, but this represents a less risk-adverse management strategy.

6. OTHER CONSIDERATIONS

- This assessment must be considered as preliminary and not equivalent to a Wild Salmon Policy status assessment since it relies primarily on the IFCRT recovery objectives and not formal WSP benchmarks. Formal WSP status assessments of the Interior Fraser Coho CUs are planned for late 2014.
- Escapement estimates, along with estimates of exploitation rate, were the primary information upon which this assessment was based. The reliably of future status assessments as well as short-term assessments of fishing impacts on Interior Fraser Coho escapements are contingent upon maintaining the current level of escapement monitoring, particularly if fishing restrictions currently in place to protect Interior Fraser Coho are eased to increase fishing opportunities for other stocks and species. Increased catch monitoring effort should also be considered to address significant uncertainties and bias in exploitation rate estimates, and to better assess the impacts of possible changes to fishing effort on Interior Fraser Coho.

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8. TABLES

Table 1. Interior Fraser Coho Management Unit average annual exploitation rate for the largest fisheries (representing 75% of the total harvest) as used in the current PSC Coho Technical Committee FRAM Base Period (1986 to 1992).

Fishery	Average Annual ER	Proportion of Total ER
SW Vancouver Island Troll	24.8434%	32.8%
NW Vancouver Island Troll	9.0375%	11.9%
North Georgia Straits Sport	8.0252%	10.6%
South Georgia Straits Sport	5.0165%	6.6%
BC Juan de Fuca Net	4.1900%	5.5%
Georgia Straits Troll	3.0114%	4.0%
WA Area 5 Sport	2.6326%	3.5%

Table 2. Summary of wild Coho Salmon escapements for individual CUs and for the Interior Fraser Coho aggregate. Escapement values shown in grey italic for the Lower Thompson, Fraser Canyon and Middle/Upper Fraser CUs are extrapolations based on observed escapements for the North and South Thompson CUs (see Section 2.1.1). Also shown (for the aggregate only, and by return year) are wild escapements, total escapements (wild spawners + 1st generation hatchery fish spawning in natural habitat), wild total returns (wild escapement + wild catch), total returns (total escapement + total catch), exploitation rates (ER), and adult recruits/spawner (wild escapement/total return). The right-most column shows smolt-adult (marine) survival estimates for Strait of Georgia wild Coho Salmon indicator stocks (see Decker and Irvine 2013, Section 11.5).

	Escapement by Conservation Unit (wild fish only)					Interior Fraser Coho aggregate						
	South	North	Lower	Mid/Upper	Fraser	Escapement		Total Return			Rec-ruits/	Smolt-adult
Year	Thom.	Thom.	Thom.	Fraser	Canyon	Wild	Total	Wild	Total	ER	spawner	survival
1975	10,613	27,618	*4,630*	*5,995*	*9,504*	58,359	58,359	182,659	182,659	68.1%		-
1976	6,506	26,198	*3,961*	*5,128*	*8,130*	49,922	49,922	156,253	156,253	68.1%		-
1977	14,096	35,220	*5,972*	*7,733*	*12,260*	75,281	75,281	235,624	235,624	68.1%		6.5%
1978	12,725	33,021	*5,540*	*7,173*	*11,372*	69,832	69,832	218,569	218,569	68.1%	3.7	9.7%
1979	15,958	22,247	*4,627*	*5,991*	*9,498*	58,320	58,320	182,538	182,538	68.1%	3.7	7.4%
1980	11,028	10,943	*2,661*	*3,445*	*5,462*	33,538	33,538	104,972	104,972	68.1%	1.4	10.1%
1981	6,235	21,265	*3,330*	*4,312*	*6,836*	41,979	41,979	131,391	131,391	68.1%	1.9	7.1%
1982	8,795	23,639	*3,928*	*5,086*	*8,063*	49,511	49,511	154,966	154,966	68.1%	2.7	4.8%
1983	8,802	21,759	*3,701*	*4,792*	*7,597*	46,651	46,651	146,014	146,014	68.1%	4.4	9.5%
1984	19,617	40,419	6,556	*9,414*	*14,925*	90,931	90,931	284,608	284,608	68.1%	6.8	9.9%
1985	22,016	18,546	4,475	*6,360*	*10,084*	61,481	61,481	192,433	192,433	68.1%	3.9	13.2%
1986	17,479	26,874	3,879	*6,955*	*11,026*	66,212	68,344	193,119	199,335	65.7%	4.1	12.5%
1987	18,722	27,416	5,889	*7,234*	*11,470*	70,730	80,559	152,835	174,073	53.7%	1.7	11.9%
1988	25,209	32,914	3,193	*9,114*	*14,449*	84,878	96,702	294,680	335,731	71.2%	4.8	18.2%
1989	16,196	23,701	3,207	*6,256*	*9,918*	59,277	69,714	167,059	196,474	64.5%	2.4	12.5%
1990	9,783	16,042	4,599	*4,049*	*6,420*	40,894	48,485	155,224	184,037	73.7%	1.9	13.2%
1991	4,842	11,703	5,413	*2,594*	*4,113*	28,665	33,545	88,871	104,001	67.7%	0.9	8.1%
1992	12,995	13,193	3,838	*4,106*	*6,510*	40,643	50,528	219,274	272,605	81.5%	3.1	11.1%
1993	2,631	6,192	11,034	*1,383*	*2,193*	23,434	29,381	188,241	236,016	87.6%	3.9	7.1%
1994	6,210	9,878	4,759	*2,523*	*4,000*	27,370	35,517	48,301	62,677	43.3%	1.4	8.0%
1995	4,070	8,477	2,692	*1,967*	*3,119*	20,326	22,996	46,364	52,454	56.2%	0.9	5.8%
1996	1,799	3,846	617	*885*	*1,403*	8,550	9,294	51,808	56,316	83.5%	1.8	5.8%
1997	1,970	5,457	4,214	*1,165*	*1,846*	14,652	18,675	24,619	31,379	40.5%	0.7	4.7%
1998	5,502	8,752	889	4,586	5,460	25,188	27,152	27,098	29,210	7.0%	1.2	3.7%
1999	3,235	8,812	1,885	1,744	4,096	19,772	22,371	21,733	24,590	9.0%	2.3	2.2%
2000	3,744	4,160	3,031	2,324	2,719	15,978	21,905	16,541	22,675	3.4%	0.9	4.2%
2001	13,264	22,733	5,379	6,346	5,971	53,693	61,408	57,796	66,101	7.1%	2.1	5.9%
2002	10,404	17,398	6,633	4,286	3,817	42,538	55,975	45,789	60,253	7.1%	2.0	5.0%
2003	3,333	5,664	1,700	3,306	4,552	18,555	21,078	21,230	24,116	12.6%	1.0	2.7%
2004	15,643	10,089	2,318	4,872	5,872	38,794	41,522	44,849	48,003	13.5%	0.7	3.7%
2005	2,088	3,957	1,787	2,292	2,513	12,637	14,064	14,524	16,164	13.0%	0.3	1.1%
2006	1,980	3,079	707	1,308	84 [1]	7,158	7,798	7,902	8,608	9.4%	0.4	1.2%
2007	12,320	23,883	6,529	10,180	2,739	55,651	58,496	62,670	65,874	11.2%	1.5	1.3%
2008	6,282	3,279	2,640	1,472	1,138	14,810	16,429	16,419	18,214	9.8%	1.2	1.1%
2009	3,837	8,617	3,396	2,325	2,308	20,483	21,991	23,145	24,848	11.5%	3.0	3.2%
2010	8,790	10,782	9,600	5,026	1,365	35,563	37,825	40,048	42,596	11.2%	0.7	1.6%
2011	4,613	7,356	5,694	3,939	3,189	24,791	26,689	28,300	30,467	12.4%	1.7	1.3%
2012	13,363	19,638	8,892	7,337	5,134	54,365	55,715	61,290	62,813	11.3%	2.8	2.2%

Table 3. Qualitative assessment of uncertainly, bias, and the causes for parameters addressed in this document.

Parameter	Uncertainty		Bias			Effect on Harvest Impact simulations
	Magnitude	Cause	Magnitude	Direction	Cause	
Exploitation rate	High	Unknown relationship of base period to present with respect to spatial distribution and encounter rates for Interior Fraser Coho, and relationship between effort and catch.	Medium	Negative	Unreported catch, drop-off and release mortality not fully accounted for.	Error/negative bias in estimates of exploitation rate in previous years (model input) will result in error/positive bias in estimates of total return and productivity, and lead to uncertainty/and overestimation of sustainable ER (model output). However, this may not be of serious consequence if the same methods are used to estimate ER going forward (see *Section 3.2*).
Escapement estimates	High (1975-1997) Medium (1998-2013)	1975-1997: No survey data for Upper /Middle Fraser CUs, or for Lower Thompson CU (1975-1983); escapements were extrapolated based on ratios of abundance with other CUs during 1998-2000). For all CUs, surveys were often infrequent and of limited coverage. 1998-2013: Surveys conducted in all CUs, but escapement extrapolated for some streams that went un-surveyed in some years; precise methods (e.g., fence counts, mark-recapture) used for some streams, but less precise visual count/AUC method used for the majority.	Medium	Negative	Not all spawning streams are surveyed. Low detection probability as a result of poor visibility conditions not fully accounted for in escapement models.	Uncertainty in 1975-1997 escapements: errors-in-variables will lead to overestimates of productivity for SR models other than time-series model; SR relationship uncertain for 1975-1993 high productivity period. Uncertainty in 1998-2012 escapements: errors-in-variables Biased-low estimates of aggregate escapement: overestimation of the probability of failing to meet IFCRT short-term and long-term objectives (20,000 and 40,000 spawners, respectively) for a given exploitation rate and productivity level.
Proportion of hatchery fish in wild escapement	Low	Estimated by factoring proportion of marked (hatchery) adults observed in carcass recoveries from enhanced streams by proportion of hatchery smolts released in those streams that were marked; carcass recovery sample sizes are often small or not representative.	Low	Negative	The proportion of hatchery fish (marked and unmarked) spawning naturally in unenhanced streams is assumed to be 0%, but hatchery adults do stray at low rates to unenhanced streams.	Uncertainty about the proportion of hatchery fish in wild escapement leads to error in estimates of adult recruits and productivity. Biased-low estimates of the proportion of hatchery fish in wild escapement leads to biased high estimates of productivity.
Stock-recruitment relationship	Medium / High	The form of the stock recruitment relationship is assumed to be one of several frequently used models. The model selection is based upon fitting to the ER and escapement time series. Biases in those time series can affect the stock recruitment model fitting and selection.	Low	Positive	Biases in the data used to select and parameterize the S-R model can lead to biased predictions of stock response to harvest.	The three models selected show similar population response at escapements above 10000 so model selection bias should not be a major issue. (Figure 16a and 16b) The biases in exploitation rates and escapement estimates however are expressed in the estimation of the stock recruitment parameters, which can lead to biased high estimates of productivity.

Table 4. Numbers of average returning adult Coho Salmon (wild escapement and wild + hatchery escapement), and the estimated proportion of hatchery fish included in total escapements by subpopulation and CU, and for the Interior Fraser Coho aggregate during the most recent generation (geometric mean for 2010-2012). The proportion of years during 1998-2012 when average escapement (3 year running geometric mean) for individual subpopulations exceeded 1,000 spawners is also shown.

Conservation Unit (CU)	Subpopulation	Escape-ment (Wild)	Escape-ment (Wild + Hatchery)	% Hatchery Fish	Proportion of Years When 3-Year Mean Escapement > 1000 Adults (1998-2012)
South Thompson	Adams River	1,535	1,535	0.0%	33.3%
	Middle/Lower Shuswap	2,716	2,716	0.0%	100.0%
	Shuswap Lake	3,792	4,020	5.7%	100.0%
	Total	8,152	8,380	2.7%	
North Thompson	Lower North Thompson	5,751	6,713	14.3%	100.0%
	Middle North Thompson	2,852	2,852	0.0%	100.0%
	Upper North Thompson	2,729	2,729	0.0%	80.0%
	Total	11,592	12,543	7.6%	
Lower Thompson	Lower Thompson	3,577	4,194	14.7%	66.7%
	Nicola	3,840	4,147	7.4%	80.0%
	Total	7,863	8,660	9.2%	
Middle/Upper Fraser	Middle Fraser	1,718	1,718	0.0%	80.0%
	Upper Fraser	3,215	3,215	0.0%	93.3%
	Total	5,257	5,257	0.0%	
Fraser Canyon	Fraser Canyon	2,817	2,817	0.0%	80.0%
Interior Fraser Coho aggregate		**36,325**	**38,314**	**5.2%**	

Table 5. Estimated percent change (negative values indicate a decline) in escapement of wild Coho Salmon for the most recent 1, 3, and 5 generations for five Interior Fraser Coho CUs and for Interior Fraser Coho as an aggregate. Percent change was computed based on the annual intrinsic rates of change in population size, which was derived from the slope coefficient for the regression of abundance (escapement or total return) on year (see Section 2.1.4). Abundance metrics were natural log-transformed and smoothed using a 3 year running average prior to computing regressions.

			Change in Escapement	
Number of Generations	Period	Population	Per Year	Total Change
1	2009-2012	South Thompson CU	13.2%	45.1%
	2009-2012	North Thompson CU	22.3%	83.0%
	2009-2012	Lower Thompson CU	19.2%	69.2%
	2009-2012	Middle/Upper Fraser CU	29.5%	117.1%
	2009-2012	Fraser Canyon CU	37.5%	159.8%
	2009-2012	Interior Fraser aggregate	20.3%	74.1%
3	2003-2012	South Thompson CU	4.0%	42.6%
	2003-2012	North Thompson CU	5.9%	67.2%
	2003-2012	Lower Thompson CU	18.2%	349.0%
	2003-2012	Middle/Upper Fraser CU	4.4%	47.8%
	2003-2012	Fraser Canyon CU [1]	-4.9%	-36.3%
	2003-2012	Interior Fraser aggregate	5.7%	64.8%
5	1998-2012	South Thompson CU	2.7%	49.8%
	1998-2012	North Thompson CU	0.7%	10.3%
	1998-2012	Lower Thompson CU	7.6%	199.9%
	1998-2012	Middle/Upper Fraser CU	2.9%	54.0%
	1998-2012	Fraser Canyon CU [1]	-4.5%	-49.9%
	1998-2012	Interior Fraser aggregate	1.6%	26.1%

Table 6. Results of regression analysis to predict the number of surveyed streams where Coho Salmon were detected (N_{detect}) as a function of escapement and the number of streams surveyed (N_{survey}). Regressions for individual CUs are based on 1998-2012 data. Asterisks indicate cases where regression coefficients are significant ($P<0.05$). All data were natural log-transformed prior to computing regressions.

		Interior Fraser Aggregate (1975-1997)	Interior Fraser Aggregate (1998-2012)	South Thompson CU	North Thompson CU	Lower Thompson CU	Middle / Upper Fraser CU
N		23	15	15	15	15	15
R^2		0.963	0.895	0.609	0.683	0.103	0.671
SEE		0.035	0.042	0.093	0.097	0.219	0.181
Constant	coeff.	-0.651*	-0.135	0.359	-0.281	-0.456	-0.950
	SE	*0.197*	*0.542*	*0.726*	*0.843*	*0.676*	*0.726*
$\ln(N_{survey})$	coeff.	1.141*	0.695*	0.573*	0.638*	0.258	0.627*
	SE	*0.073*	*0.130*	*0.200*	*0.256*	*0.225*	*0.160*
ln(escape-ment)	coeff.	-0.002	0.124*	0.100*	0.145*	-0.025	0.200*
	SE	0.019	0.020	0.036	0.039	0.073	0.081

Table 7. Summary of the parameter estimates determined for each model and time series in the harvest impact analyses. We implemented a Markov chain Monte Carlo (MCMC) procedure in the Stan programming language to estimate posterior probability distributions of the model parameters and the standard deviation (sd) of the models in log space.

Model	Time Series	Model Parameter Values				Recruitment Variability	
Hockey Stick	1975-2012	alpha	1.997	S*	63552	sd	0.69
Beverton-Holt	1975-2012	a	401106.90	b	177521	sd	0.70
Ricker	1975-2012	a	0.774	b	7.10E-07	sd	0.70
Hockey Stick	1994-2012	alpha	1.563	S*	23448	sd	0.56
Beverton-Holt	1994-2012	a	70736	b	25761	sd	0.56
Ricker	1994-2012	a	0.849	b	2.16E-05	sd	0.54

Table 8. Akaike Information Criterion (AIC) values calculated for each model and time series. The model with the lowest AIC is considered to be the model that best fits the data. The weighted AIC values indicate to what degree any model does a better job of fitting the data.

Model	Time Series	AIC	WAIC
Hockey Stick	1975-2012	166.84	1
Ricker	1975-2012	191.52	0
Beverton-Holt	1975-2012	329.45	0
Ricker	1994-2012	176.04	1
Beverton-Holt	1994-2012	534.83	0
Hockey Stick	1994-2012	591.58	0

Table 9. Results of harvest scenario analysis to determine the probability of meeting the short-term and long-term recovery objectives for the 1994-2012 (low) productivity regime at a given exploitation rate and for a given generation. A probability value represents the probability that the geometric mean escapement is greater than the short-term or the long-term recovery objective.

	1994-2012 (Low Productivity Regime)					
	Short-Term (20,000 Spawners)			Long-Term (40,000 Spawners)		
ER	One Generation	Two Generations	Three Generations	One Generation	Two Generations	Three Generations
0%	0.75	0.84	0.87	0.00	0.23	0.31
5%	0.72	0.80	0.83	0.00	0.19	0.26
10%	0.69	0.76	0.79	0.00	0.16	0.22
15%	0.65	0.71	0.73	0.00	0.12	0.17
20%	0.60	0.66	0.67	0.00	0.09	0.13
25%	0.56	0.59	0.59	0.00	0.07	0.09
30%	0.51	0.52	0.50	0.00	0.05	0.06
40%	0.39	0.36	0.31	0.00	0.02	0.02
60%	0.15	0.07	0.03	0.00	0.00	0.00

Table 10. Results of harvest scenario analysis to determine the probability of meeting the short-term and long-term recovery objectives for the 1978-2012 (full time series) productivity regime at a given exploitation rate and for a given generation. A probability value represents the probability that the geometric mean escapement is greater than the short-term or the long-term recovery objective.

	1978-2012 (Full Series Productivity Regime)					
	Short-Term (20,000 Spawners)			Long-Term (40,000 Spawners)		
ER	One Generation	Two Generations	Three Generations	One Generation	Two Generations	Three Generations
0%	0.98	0.97	0.98	0.18	0.70	0.86
5%	0.98	0.96	0.97	0.16	0.66	0.83
10%	0.98	0.95	0.96	0.14	0.62	0.79
15%	0.97	0.93	0.95	0.12	0.58	0.74
20%	0.96	0.91	0.93	0.10	0.53	0.69
25%	0.96	0.89	0.90	0.09	0.47	0.63
30%	0.94	0.86	0.87	0.07	0.42	0.56
40%	0.91	0.77	0.75	0.05	0.30	0.40
60%	0.78	0.44	0.34	0.01	0.08	0.09

9. FIGURES

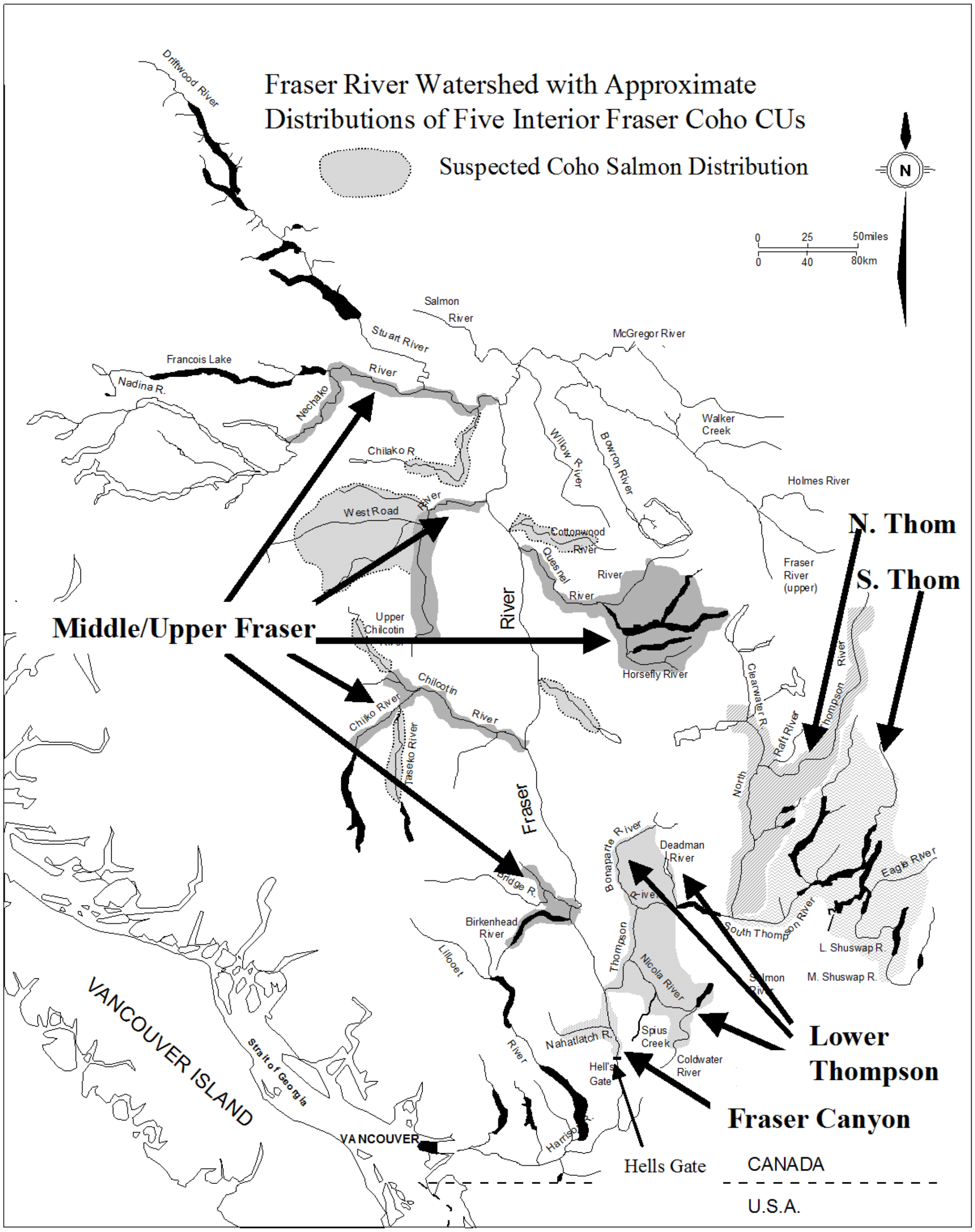

Figure 1. Approximate distribution within the Fraser River watershed of five CUs of Coho Salmon (North Thompson, South Thompson, Lower Thompson, Fraser Canyon, and Middle/Upper Fraser) within the interior Fraser River watershed (reproduced from Irvine 2002). Shaded areas represent the suspected (unconfirmed) distribution of Coho for the Middle/Upper Fraser CU, and the known (approximate) distribution for the remaining four CUs.

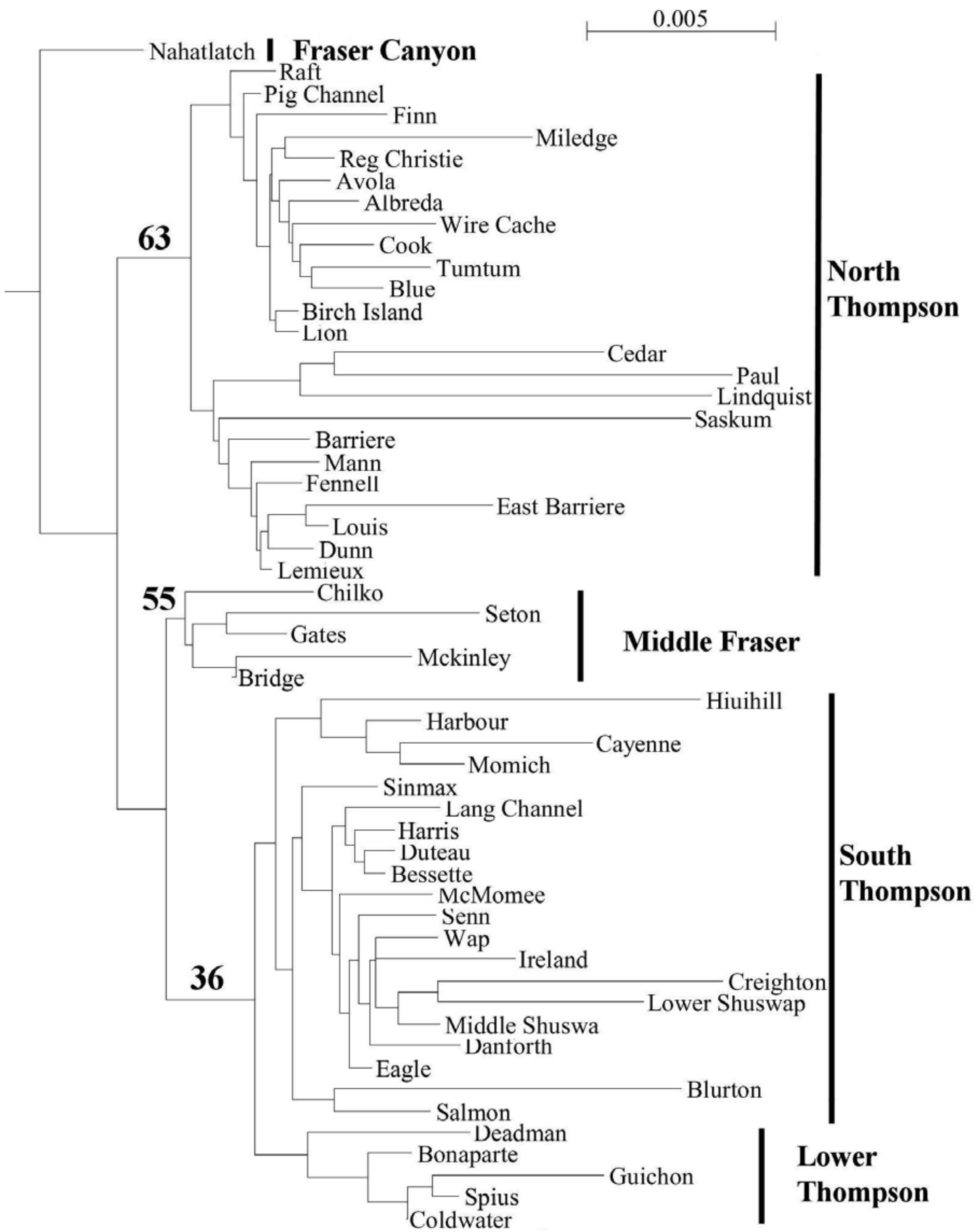

Figure 2. Neighbour-joining dendrogram of Cavalli-Sforza and Edwards (1967) chord distance for Interior Fraser River Coho Salmon populations surveyed at 15 microsatellite loci. Bootstrap values (in bold) at major tree nodes indicate the percentage of 500 trees where populations beyond the node clustered together. Figure is updated from Supplemental Figure 1 in Beacham et al. (2011); courtesy T. Beacham, DFO Nanaimo. Scale at upper right indicates coancestry coefficient (FST) values.

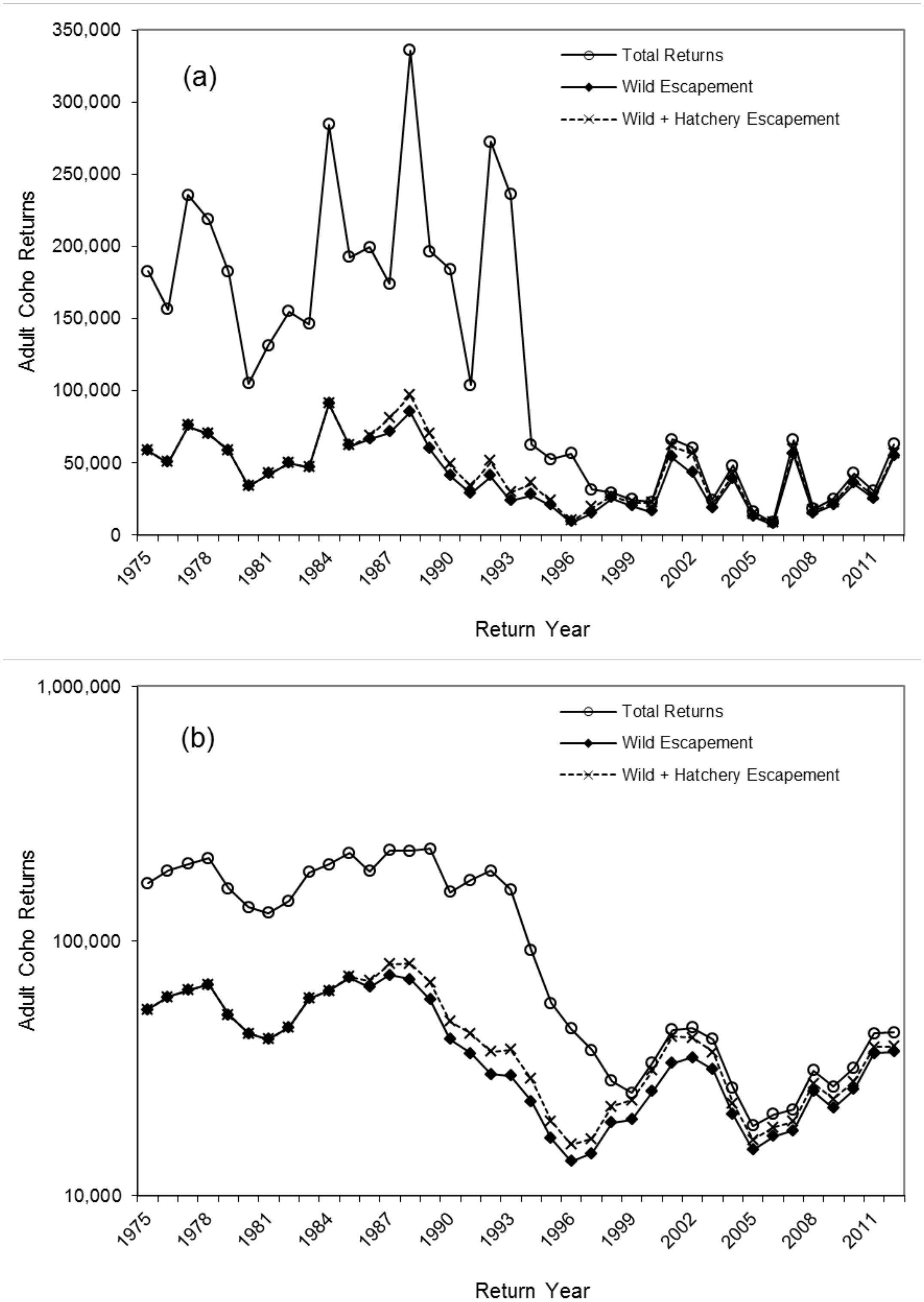

Figure 3. Reconstructed time series of wild Coho Salmon escapements and total escapements (wild + hatchery fish) and total returns (total escapement + catch) for the interior Fraser River watershed during 1975-2012 (data are provided in Table 2). Graph (a) shows annual estimates; graph (b) shows the same data with escapement and total return values smoothed using a 3-year running average and plotted on a log_{10} scale.

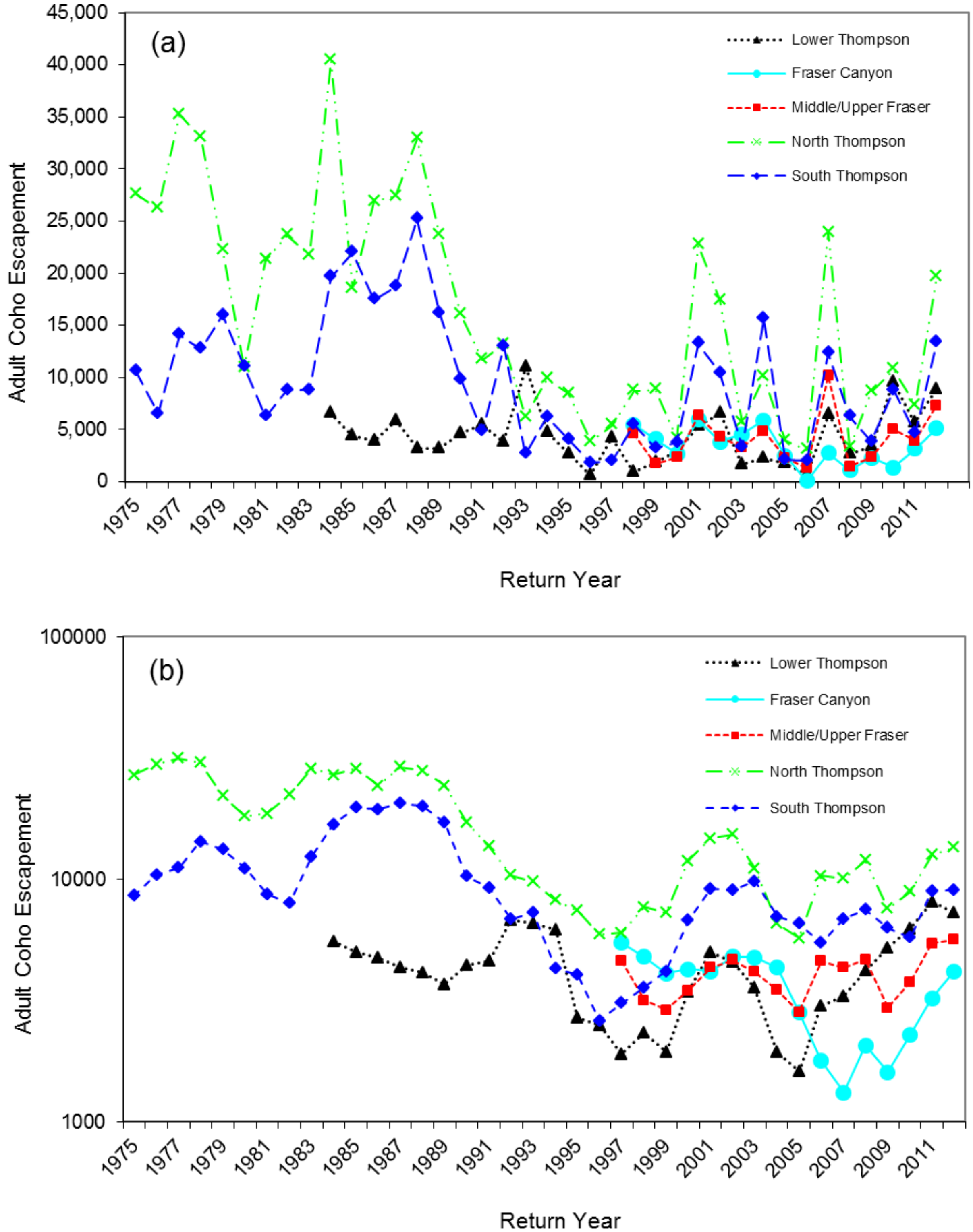

Figure 4. Reconstructed time series of wild Coho Salmon escapements for five CUs within the interior Fraser River watershed during 1975-2012 (data are provided in Table 2). Graph (a) shows annual estimates; graph (b) shows the same data with abundance values smoothed using a 3-year running average and plotted on a log_{10} scale.

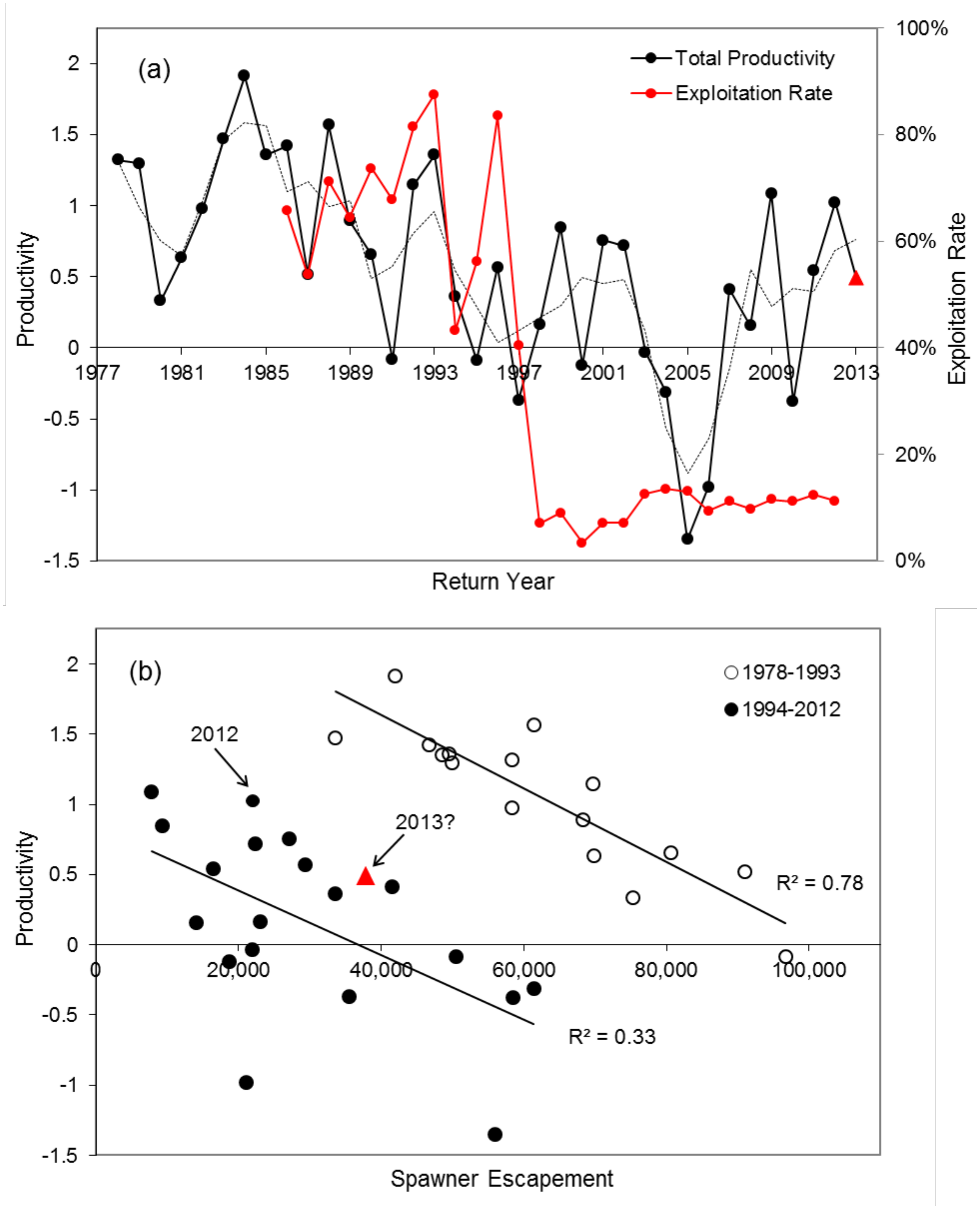

Figure 5. Graph (a) shows the time series of productivity (ln[recruits/spawner]) (1978-2012) and exploitation rate estimates (1986-2012) for Interior Fraser Coho Salmon. The black dotted line shows the 3-year running arithmetic mean for productivity. Negative productivity values represent years of negative population growth when the population is unable to replace itself (i.e., < 1 recruit per spawner), even in the absence of exploitation. The preliminary estimate for 2013 appears as a solid red triangle. Graph (b) plots of productivity versus aggregate brood escapement for Interior Fraser Coho for two time periods: 1978-1992 and 1993-2012. The coefficient of determination (R^2) values shown in graph (b) indicate the log-linear regression fit for productivity versus brood escapement for the two periods.

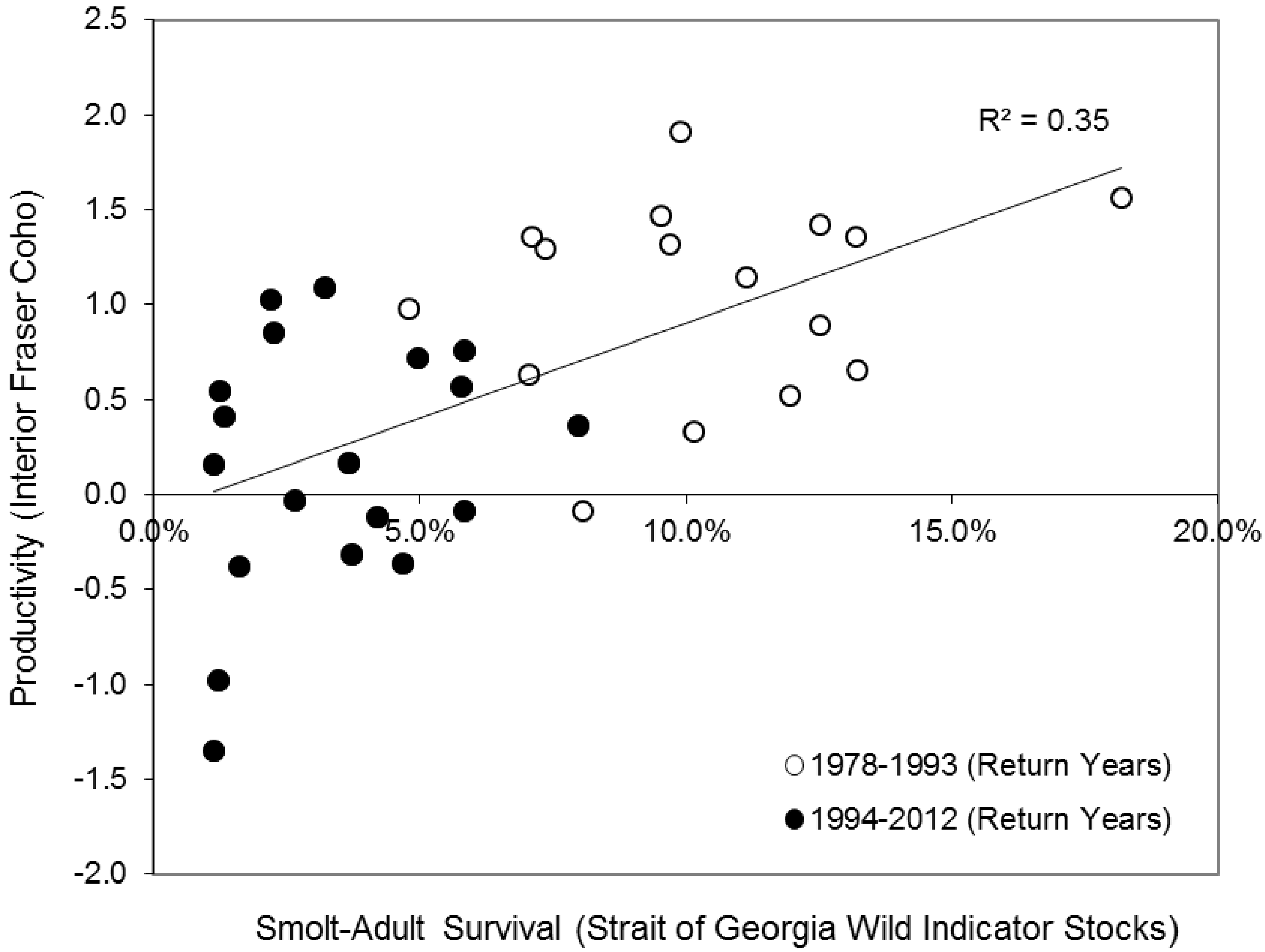

Figure 6. Plots of productivity (ln[recruits/spawner]) for the Interior Fraser Coho aggregate versus smolt-adult (marine) survival estimates for Strait of Georgia wild Coho Salmon indicator stocks (see Decker and Irvine 2013, Section 11.5) for two distinct productivity regimes: 1978-1993 (return years) and 1994-2012. The R^2 value indicates the log-linear regression fit for IFC productivity versus SOG smolt-adult survival for the entire time series.

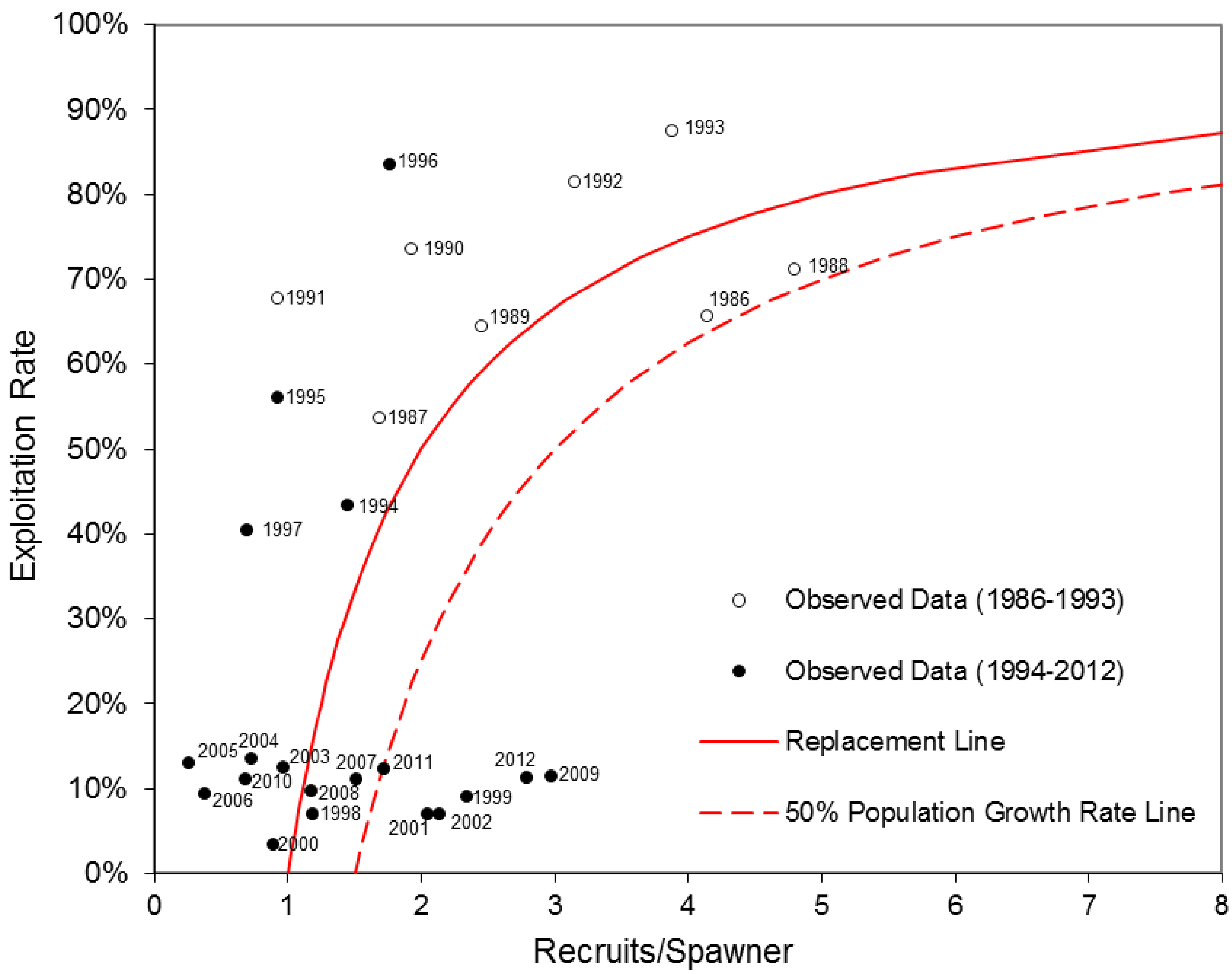

Figure 7. Plots of observed combinations of recruits per spawner (adult return year) and exploitation rate (adult return year) during 'high productivity' (1986[18]-1993) and 'low productivity' (1994-2012) periods, in relation to isopleths representing the line of replacement (1.0 post-fishing recruits per spawner) and the line of 50% population growth (1.5 post-fishing recruits per spawner). The regions to the left and right of the replacement line represent negative and positive population growth, respectively.

[18] Year-specific exploitation rates are not available for years prior to 1986 (see *Section 3.1*).

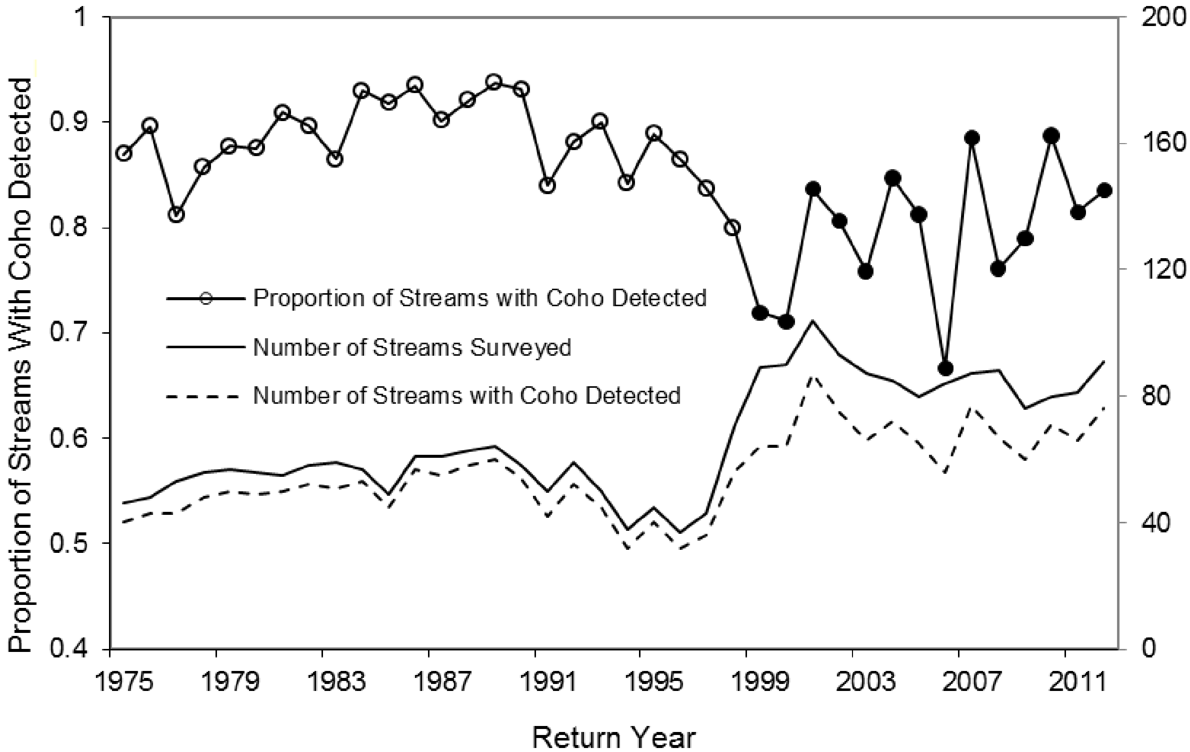

Figure 8. Trend in the number of streams in the interior Fraser River watershed where escapement surveys were conducted (N_{survey}), and in the number of streams in which Coho Salmon were detected (N_{detect}) each year during 1975-2012 (scale shown on right vertical axis). Also shown (scale on left vertical axis) is the proportion of surveyed streams where Coho Salmon were detected (P_{detect}) each year during 1975-1997 (open circles), and during 1998-2012, following the expansion of the survey program (solid circles).

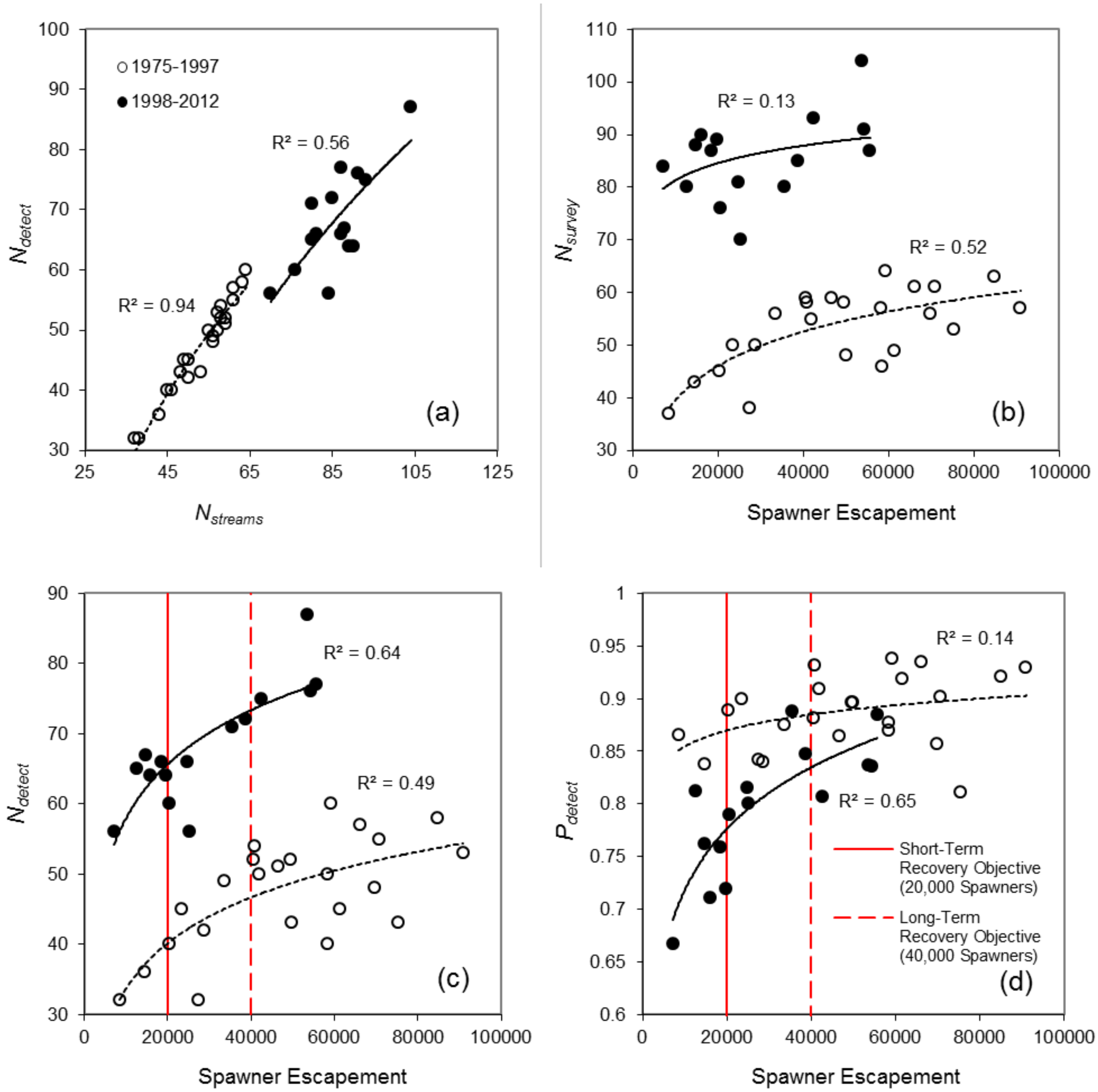

Figure 9. Graph (a) shows the number of surveyed streams in the interior Fraser River watershed where Coho Salmon were detected (N_{detect}) each year during 1975-1997 (open circles) and 1998-2012 (solid circles) versus the total number of streams surveyed (N_{survey}); graph (b) shows N_{survey} versus aggregate escapement; graph (c) shows N_{detect} versus aggregate escapement; and graph (d) shows the proportion of surveyed streams where Coho Salmon were detected (P_{detect}) versus aggregate escapement. The coefficient of determination (R^2) values shown in each graph indicate the log-linear regression relationship between the two variables for each time period. The solid and dashed vertical lines in graphs (c) and (d) represent minimum aggregate escapements necessary to achieve abundance-based short- and long-term recovery objectives proposed by the Interior Fraser Coho Recovery Team (see Section 2.2.5).

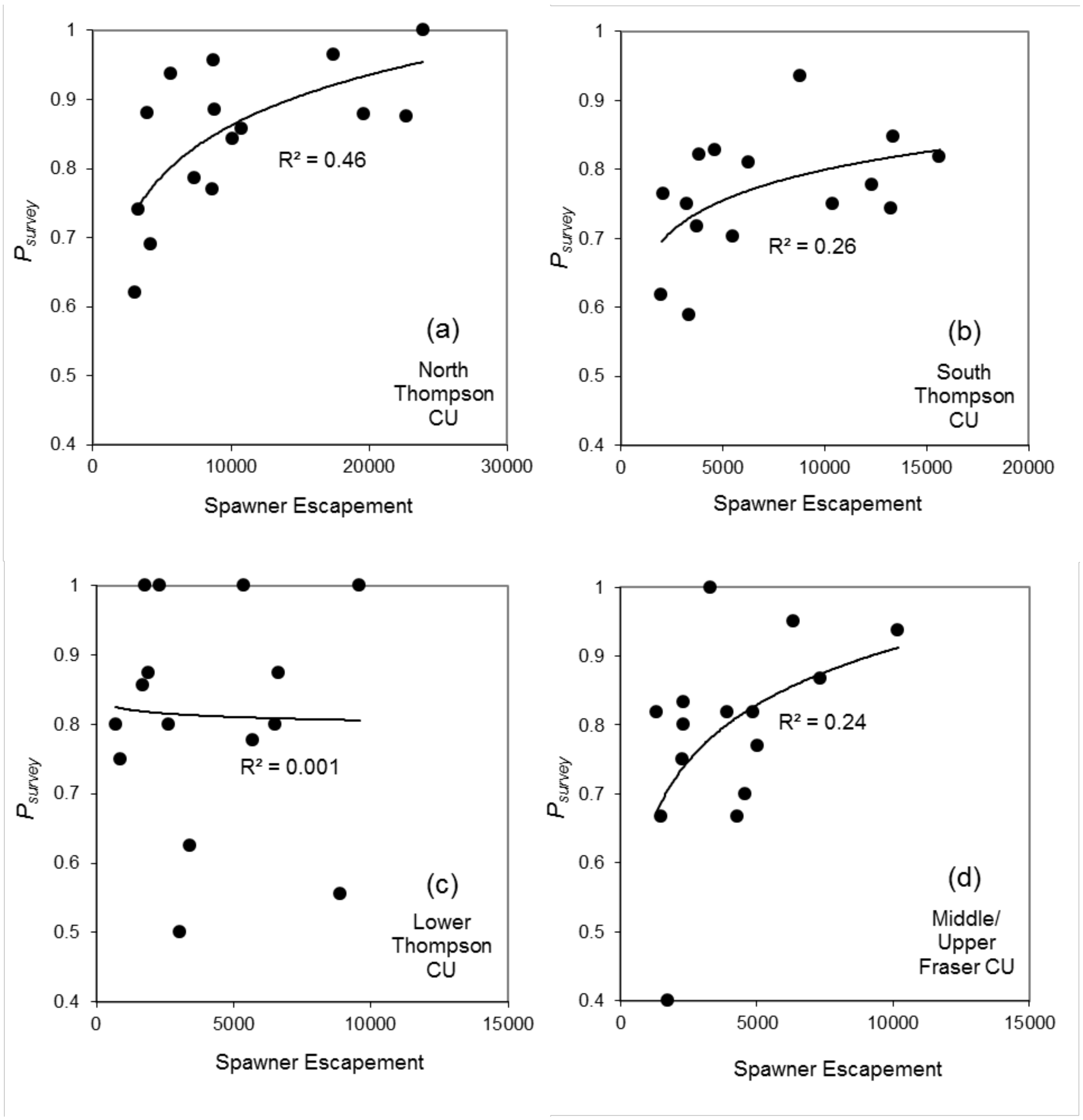

Figure 10. The proportion of surveyed streams (P_{survey}) in four CUs in the interior Fraser River watershed where Coho Salmon were detected (P_{detect}) each year during 1998-2012 versus escapement to the CU. The coefficient of determination (R^2) value shown in each graph indicates the log-linear regression relationship between the two variables.

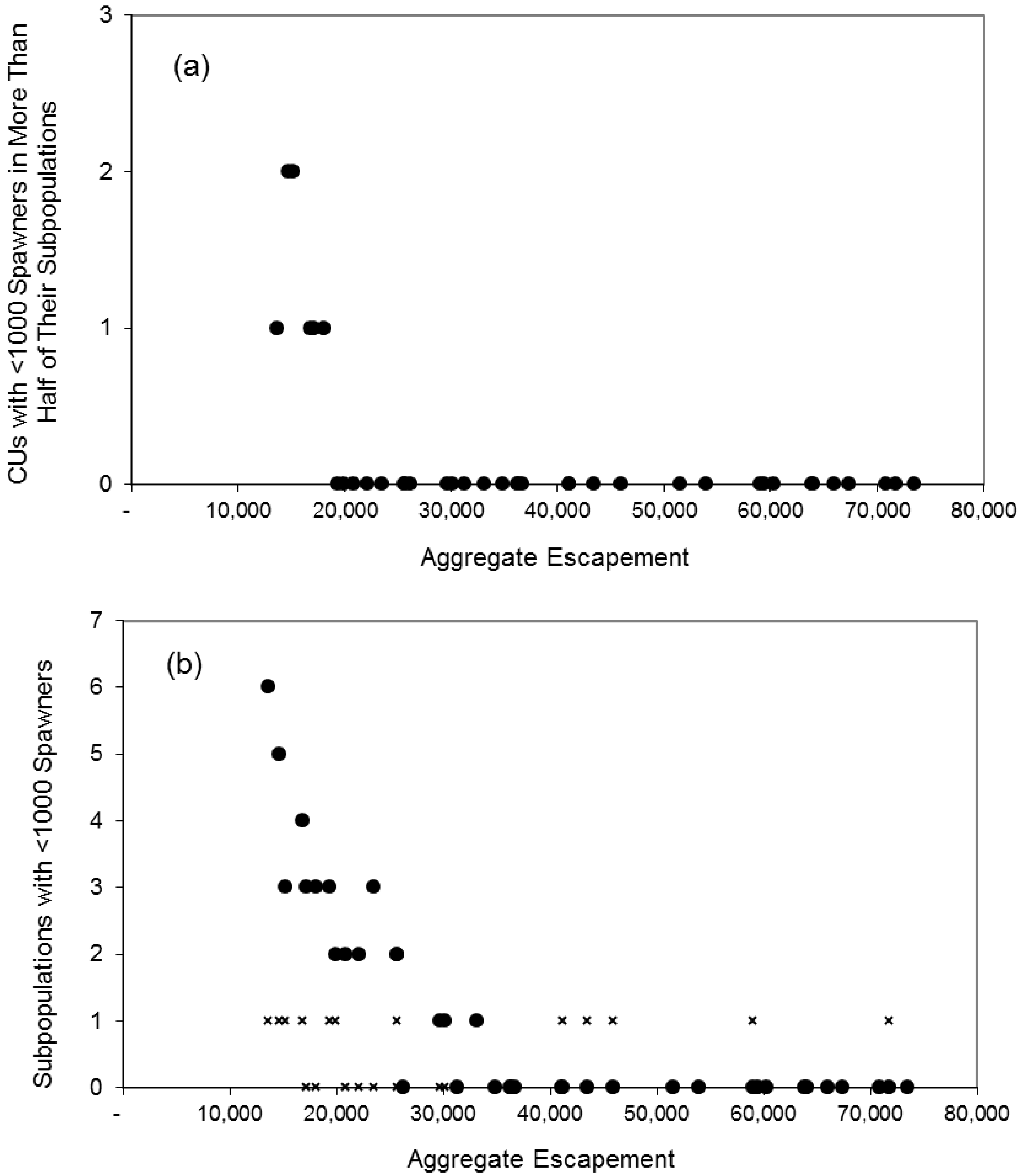

Figure 11. Graph (a) shows the number of CUs (5 in total) within the Interior Fraser Coho Management Unit with less than 1,000 spawners (3-year running geometric mean) in more than half of their subpopulations versus aggregate annual escapement for the management unit (3-year running geometric mean) during 1975-2012 (wild spawners only); Graph (b) shows the number of subpopulations (10 subpopulations excluding the Lower Thompson) within the management unit with less than 1,000 spawners (3-year running geometric mean) versus aggregate annual escapement (3-year running geometric mean) during 1975-2012 (solid circles). The Lower Thompson subpopulation is plotted separately ('x' symbols; see Section 2.2.5).

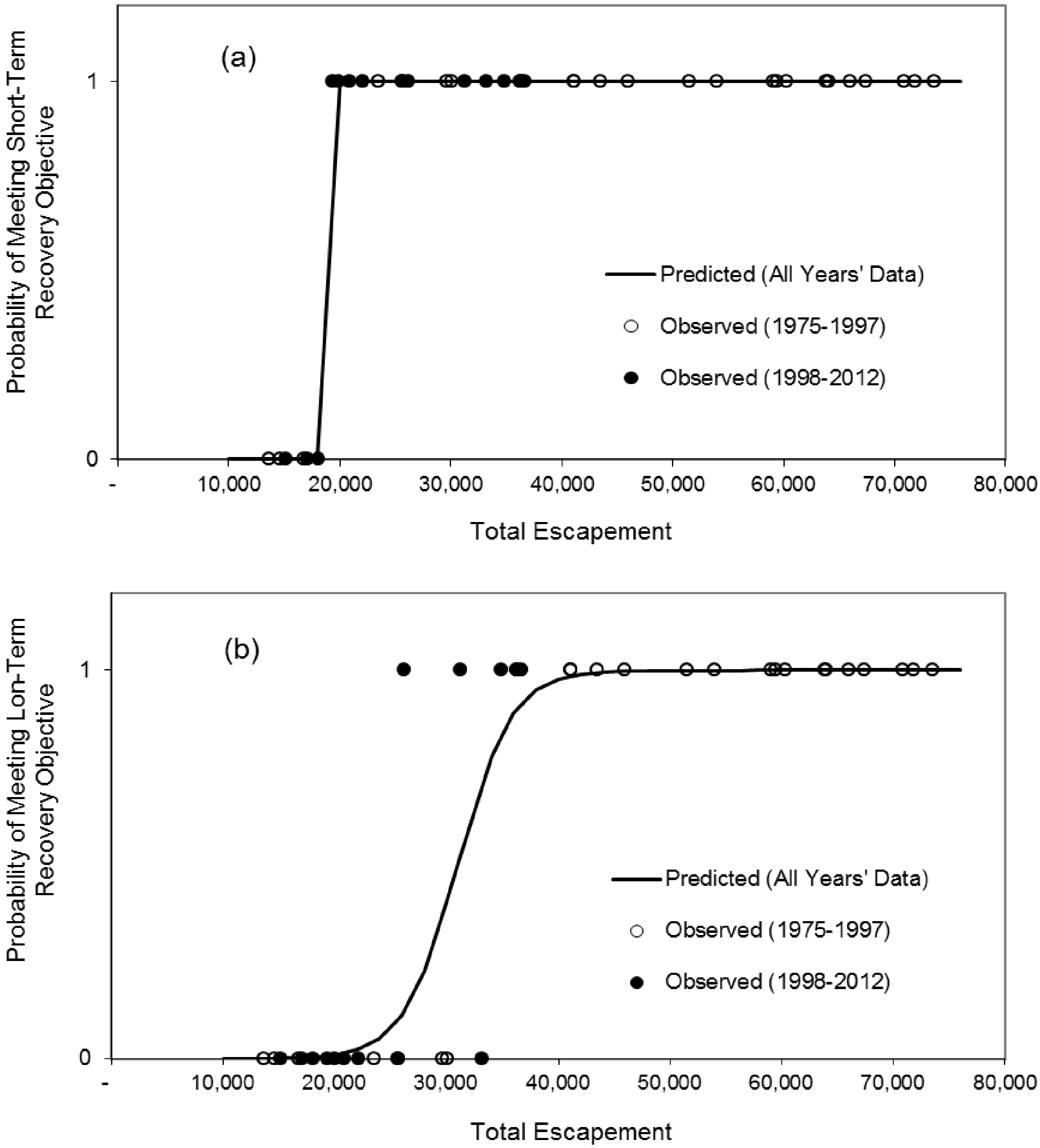

Figure 12. Graph (a) shows the probability of meeting the short-term recovery objective of all five Interior Fraser Coho CUs having 1,000 spawners (3-year running geometric mean) in half or more of their subpopulations at varying aggregate escapement levels. Open and solid circles represent observed results (0 = objective not met, 1=objective met) for 1975-1997 and 1998-2012, respectively; solid line shows predicted probabilities from the logistic regression model (all years' data); Graph (b) shows the probability of meeting the long-term recovery objective of all 11 Interior Fraser Coho subpopulations having 1,000 spawners (3-year running geometric mean) at varying aggregate escapement levels. Open and solid circles represent observed results for 1975-1997 and 1998-2012, respectively; solid line shows predicted probabilities from the logistic regression model (all years' data).

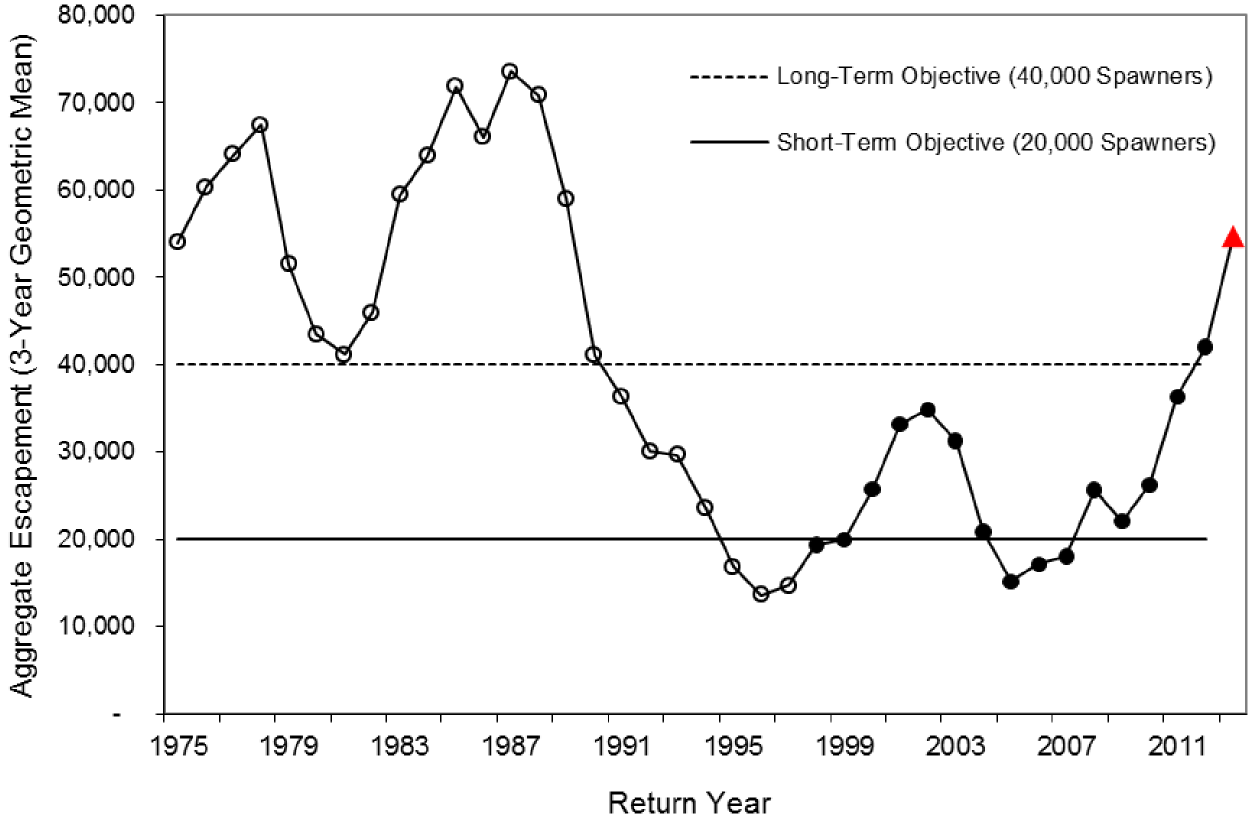

Figure 13. Total escapement (3 year running geometric mean) of Interior Fraser Coho during 1975-2012 relative to short term and long-term recovery objectives proposed by the Interior Fraser Coho Recovery Team. Values for post-1998 recovery period appear as solid circles, the preliminary value for 2013 is indicated by a solid red triangle.

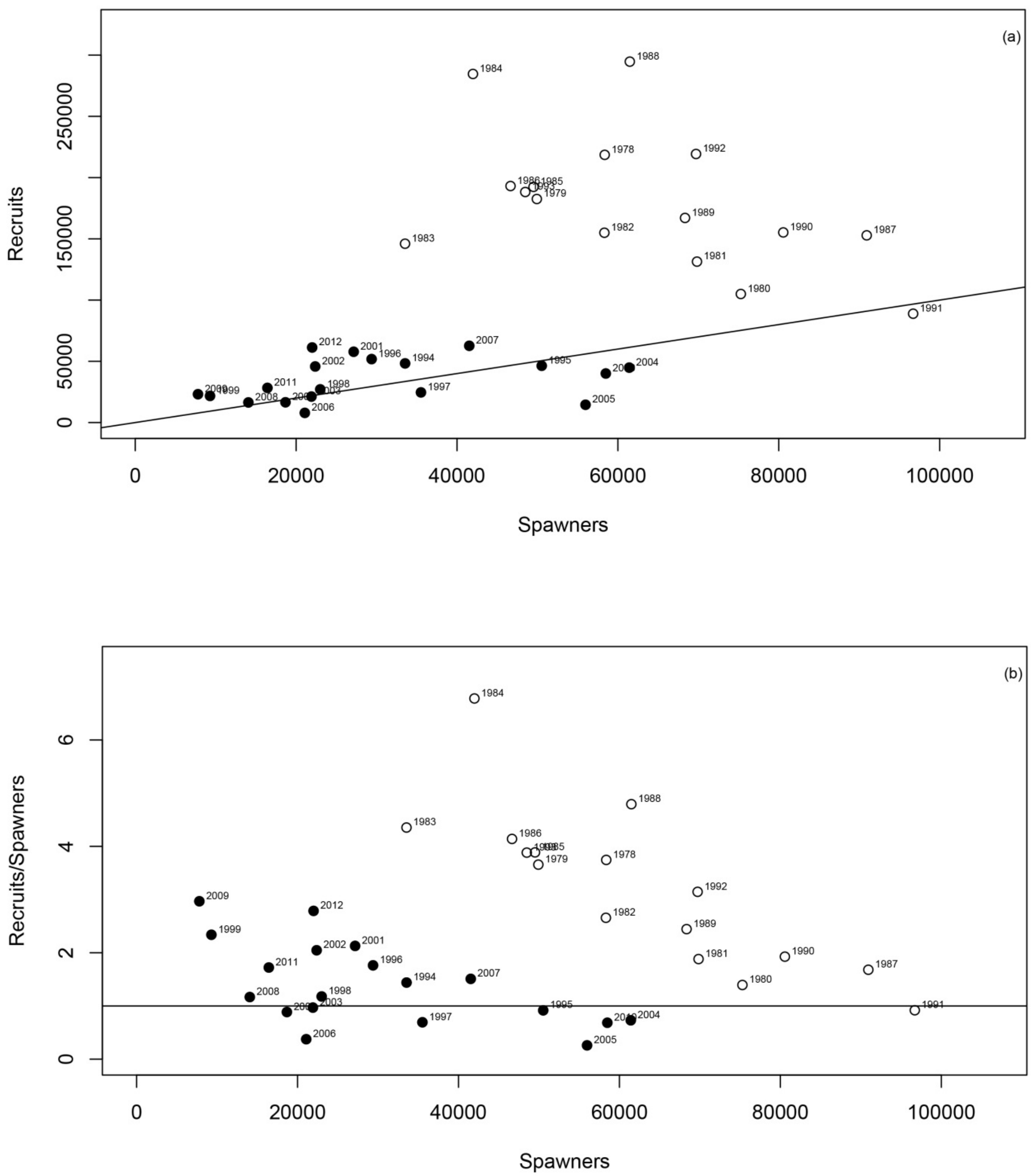

Figure 14. Time series of recruits versus spawners (a) and recruits per spawner versus spawners (b). Data points are labelled according to return year (recruits). The solid circles indicate the 1994-2012 low productivity regime; the open circles indicate the 1978-1993 high productivity regime.

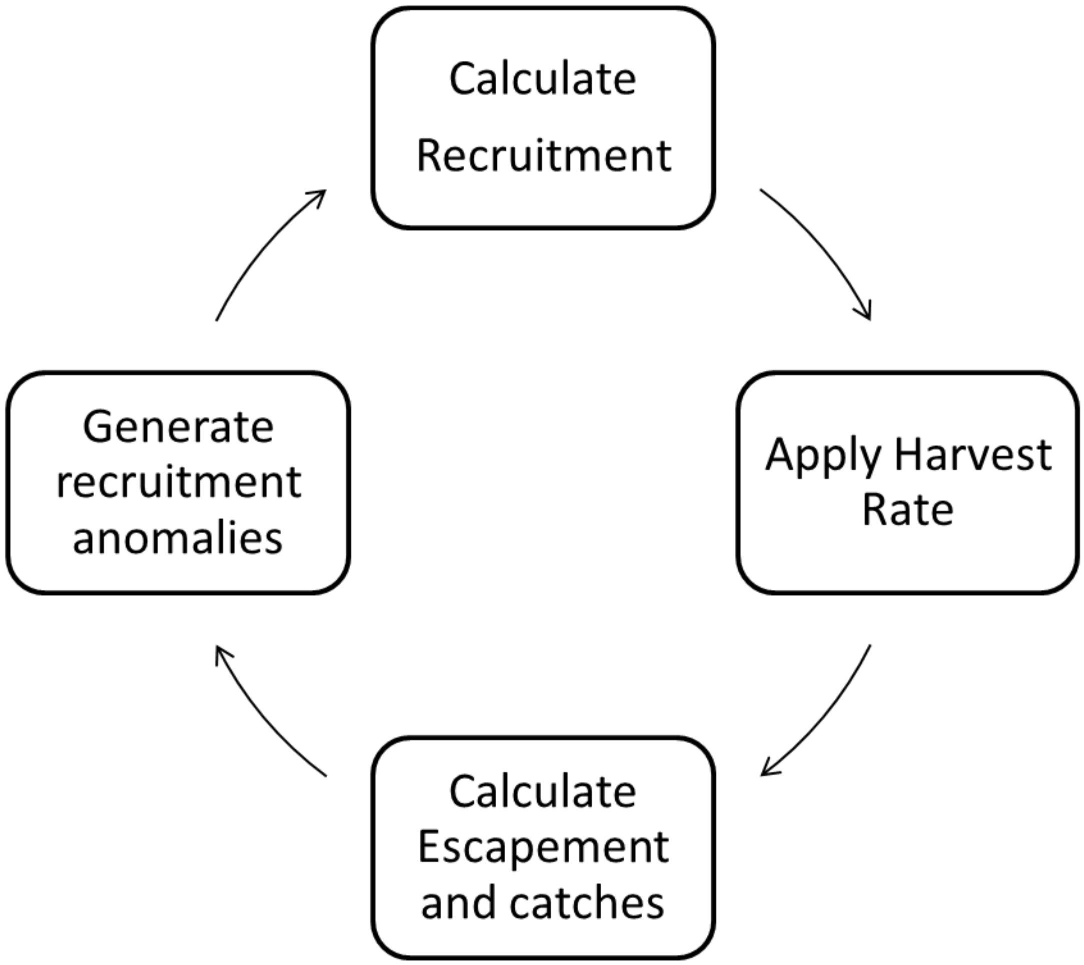

Figure 15. Simple closed-loop simulation model schematic (adapted from Walters and Martell 2004).

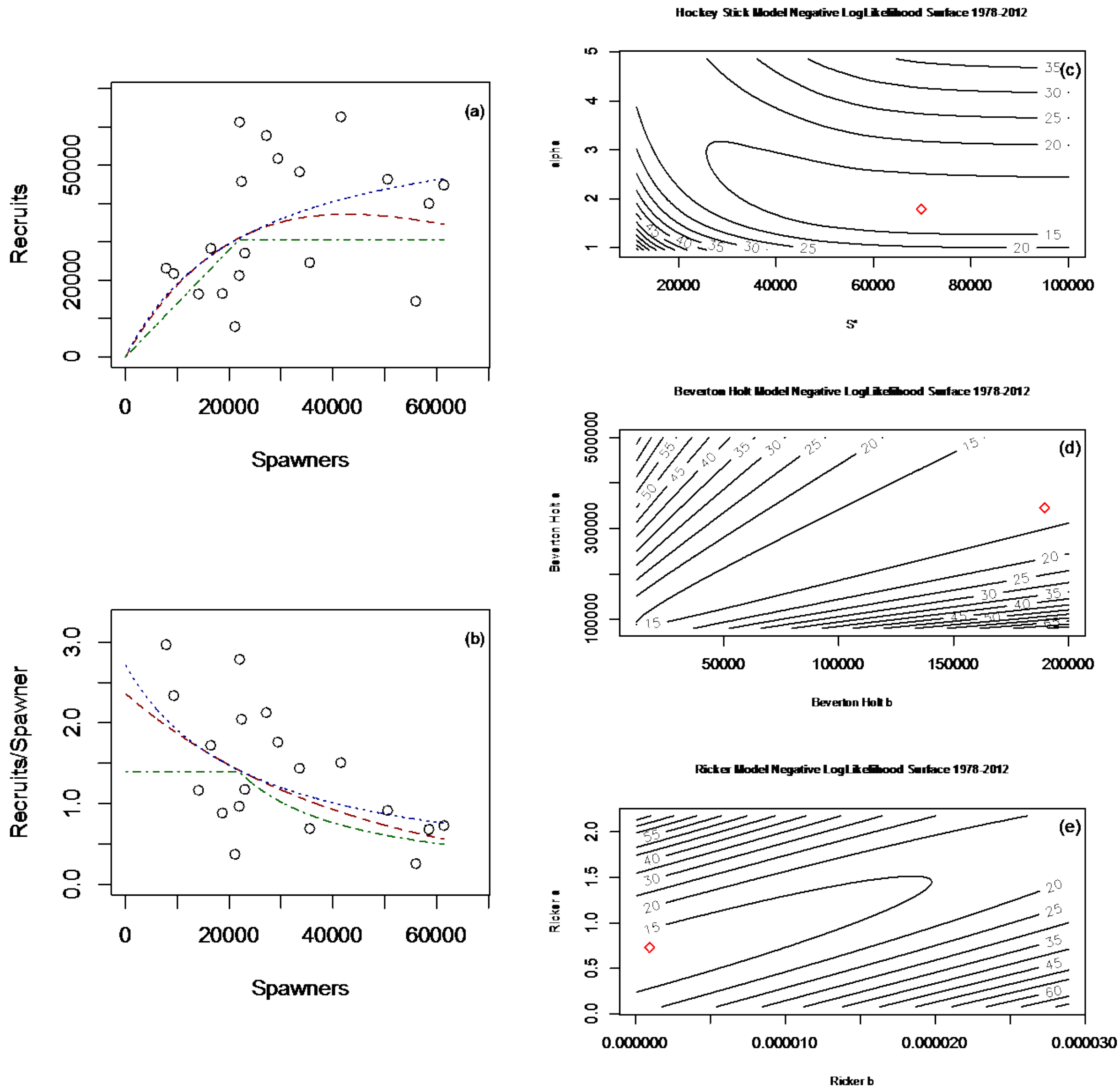

Figure 16. Model fits of the three stock recruitment relationships to the 1994-2012 time series (low productivity) of spawners and recruits. Graph (a) shows recruits vs. spawners; graph (b) shows recruits/spawner vs. spawners. On plots (a) and (b) the green dot-dashed line is the best fit for the Hockey Stick model, the blue dotted line is the best fit for the Beverton-Holt model, and the red dashed line is the best fit for the Ricker model. Graphs (c), (d) and (e) are plots of likelihood surfaces with the red diamonds indicating the maximum likelihood estimates for the stock recruitment parameters. Graph (c) is the Hockey Stick model, graph (d) is the Beverton-Holt model, and graph (e) is the Ricker model.

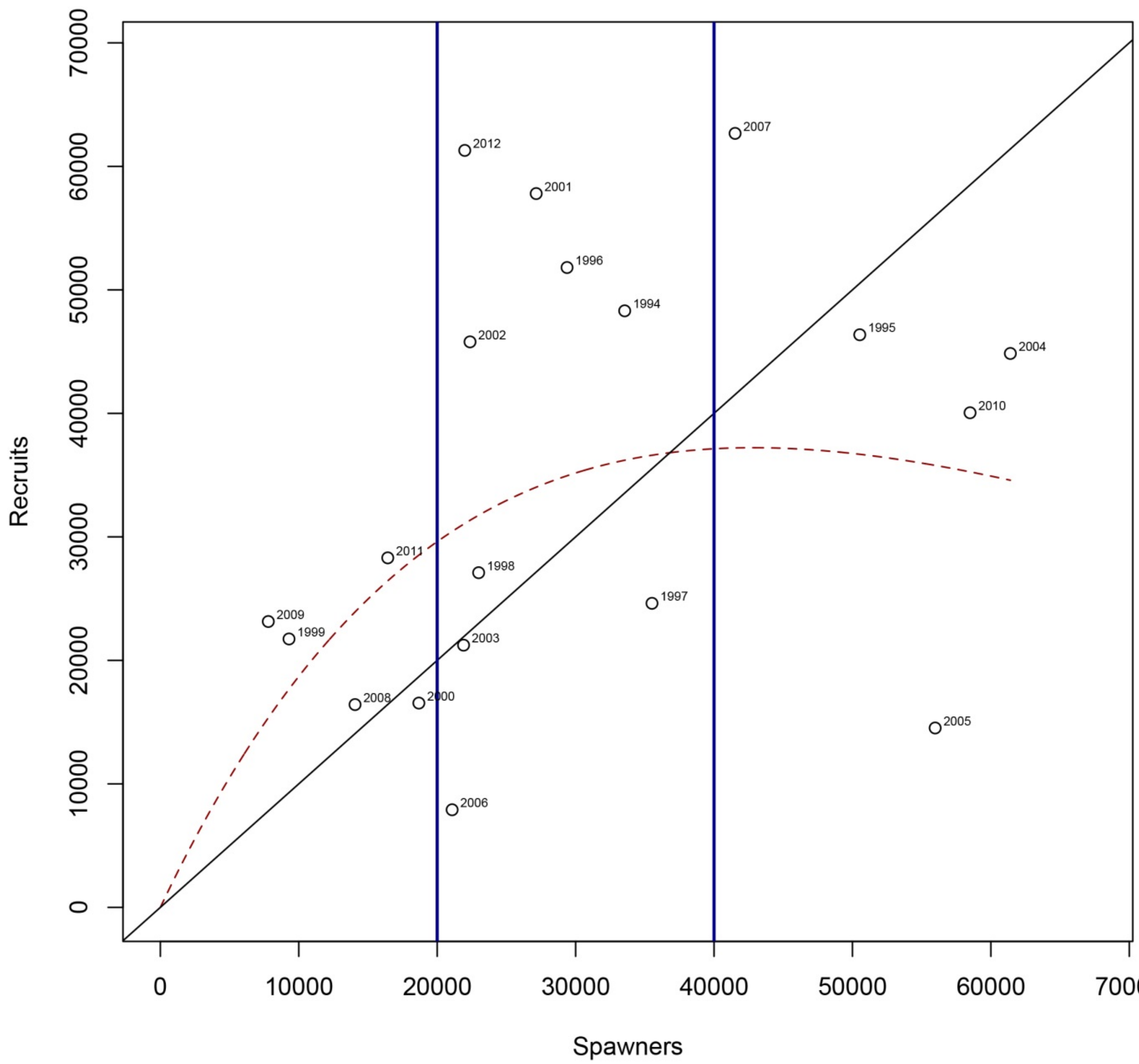

Figure 17. Observed recruits vs. spawners for the 1994-2012 (low productivity) period (open circles), with the Ricker model fit to the data shown as a red dashed line. The replacement line (recruits=spawners) is shown as a solid black line.

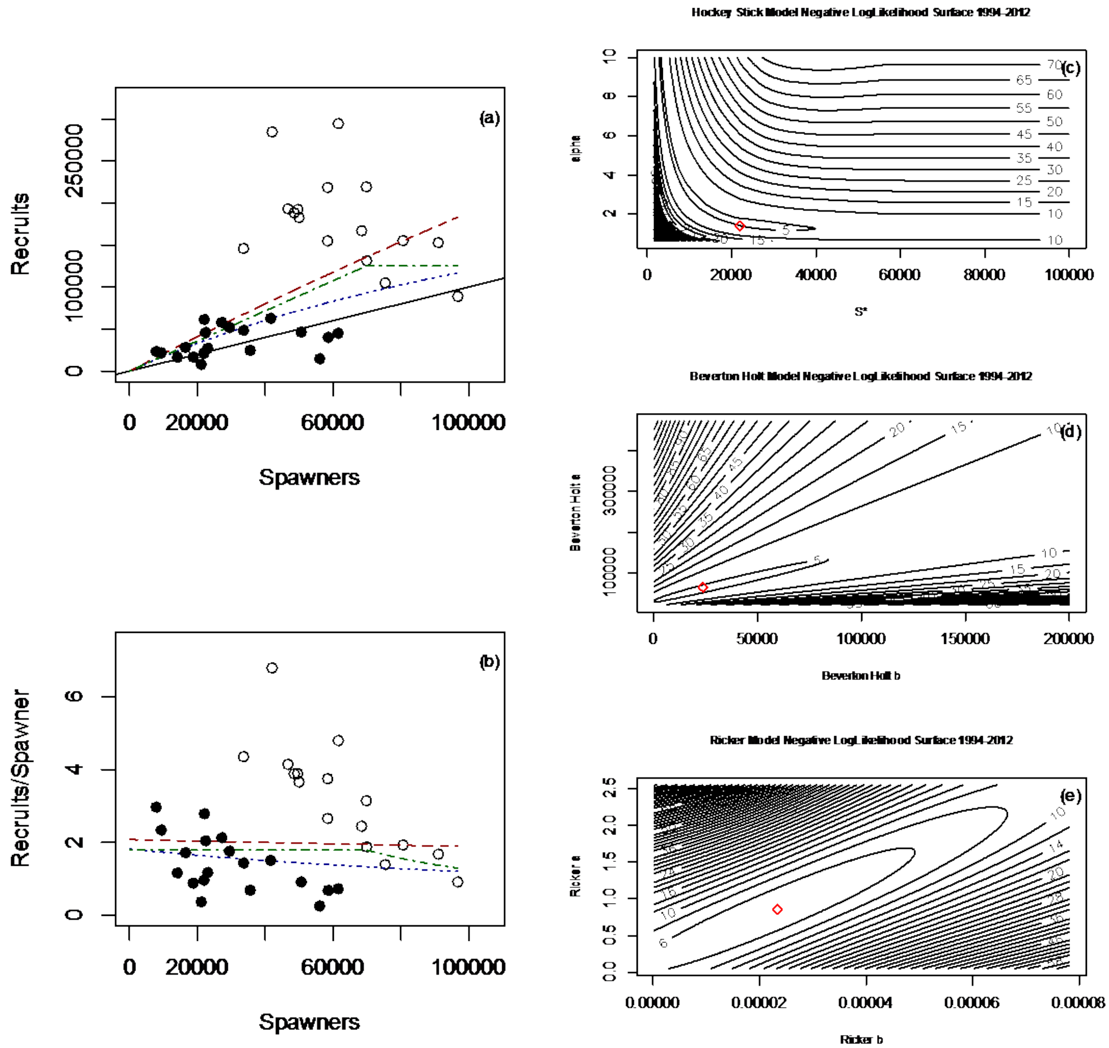

Figure 18. Model fits of the three stock recruitment relationships to the 1978-2012 time series of spawners and recruits. Graph (a) shows recruits vs. spawners; graph (b) shows recruits/spawner vs. spawners. On plots (a) and (b) the green dot-dashed line is the best fit for the Hockey Stick model, the blue dotted line is the best fit for the Beverton-Holt model, and the red dashed line is the best fit for the Ricker model. Graphs (c), (d) and (e) are plots of likelihood surfaces with the red diamonds indicating the maximum likelihood estimates for the two stock recruitment parameters. Graph (c) is the Hockey Stick model, graph (d) is the Beverton-Holt model, and graph (e) is the Ricker model.

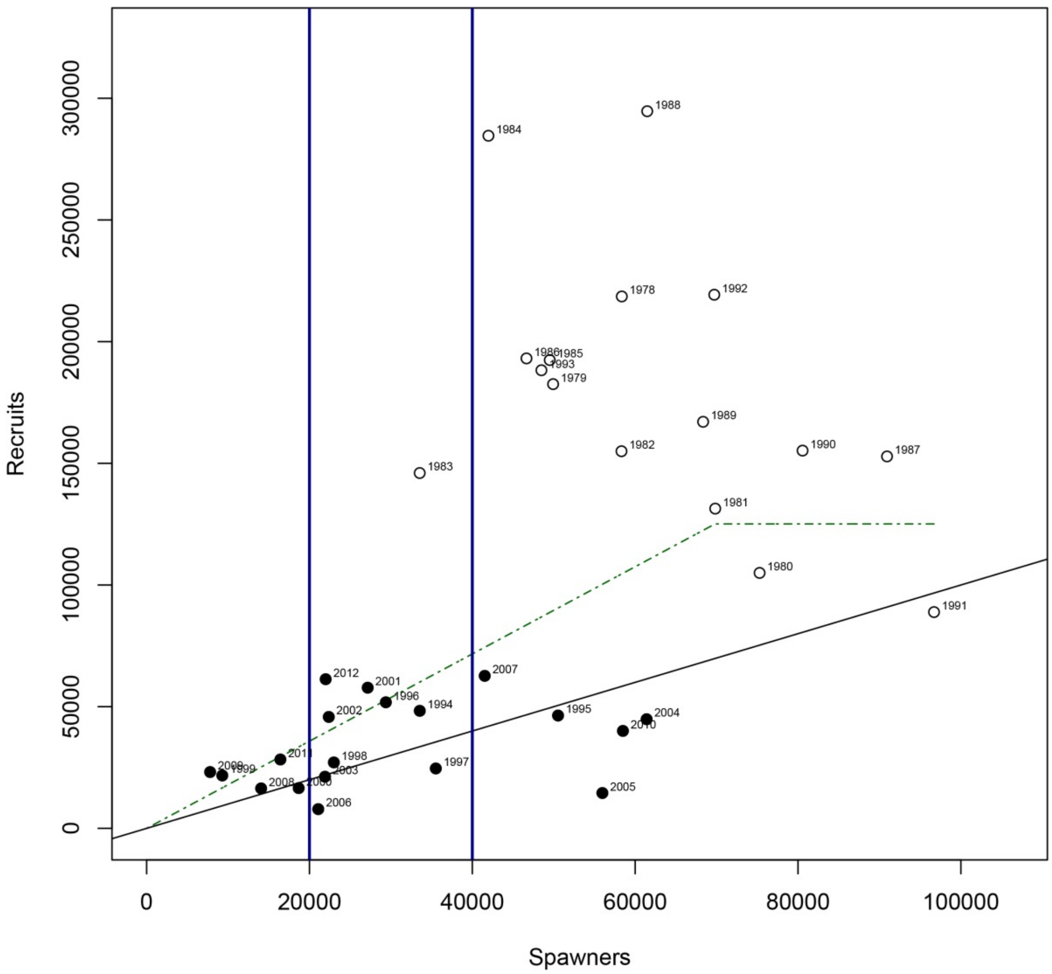

Figure 19. Observed recruits vs. spawners for the full time series (1978-2012) (open circles), with the Ricker model fit to the data shown as a green dashed line. The replacement line (recruits=spawners) is shown as a solid black line.

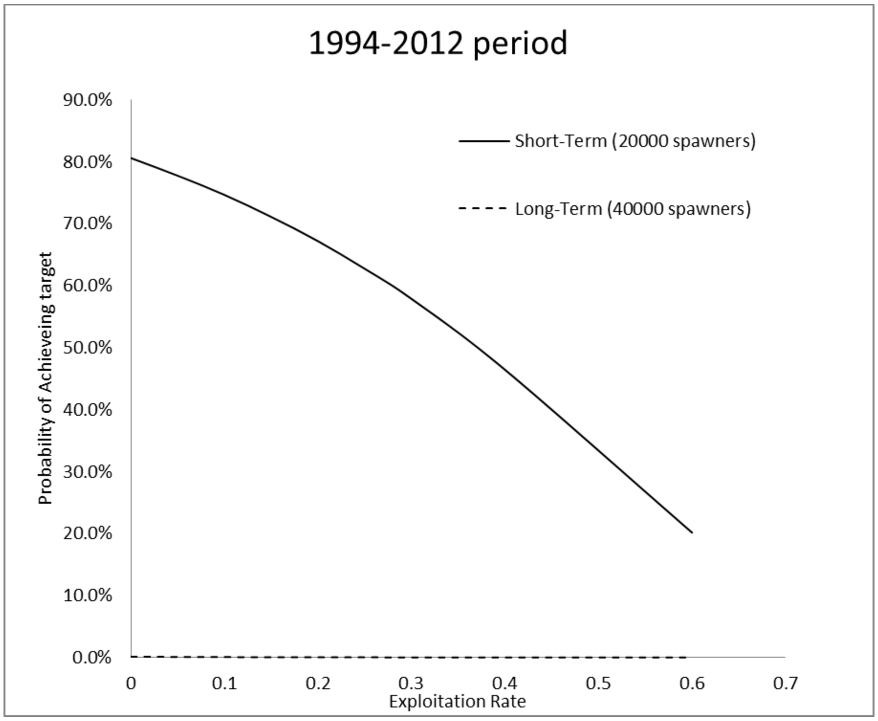

Figure 20. The probability of achieving the three year geometric mean escapement target after one generation with a productivity regime represented by the 1994-2012 period, (i.e., low productivity).

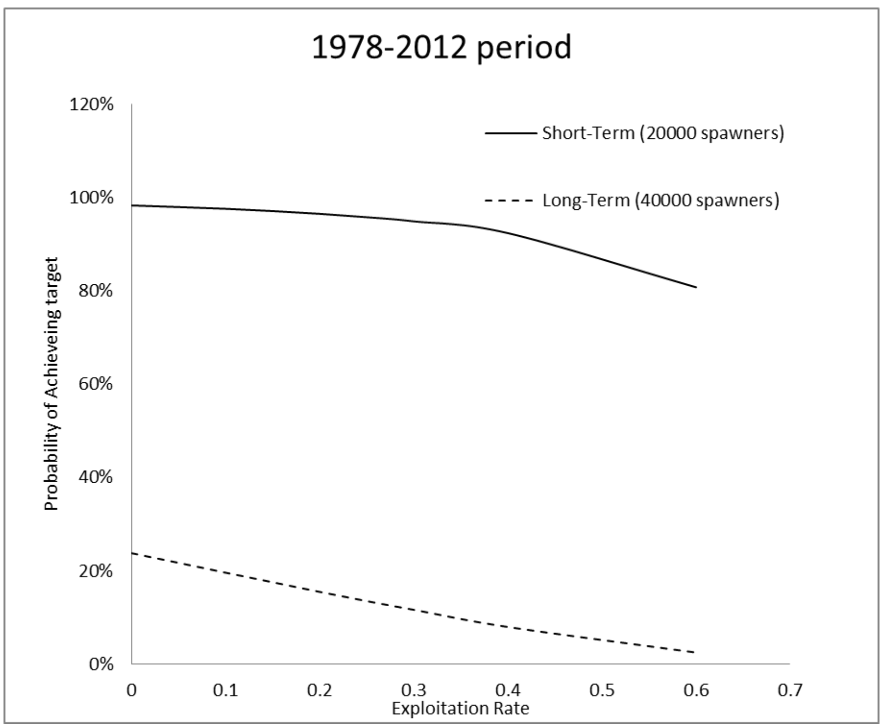

Figure 21. The probability of achieving the three year geometric mean escapement target after one generation with a productivity regime represented by the 1978-2012 period, (i.e., full time series).

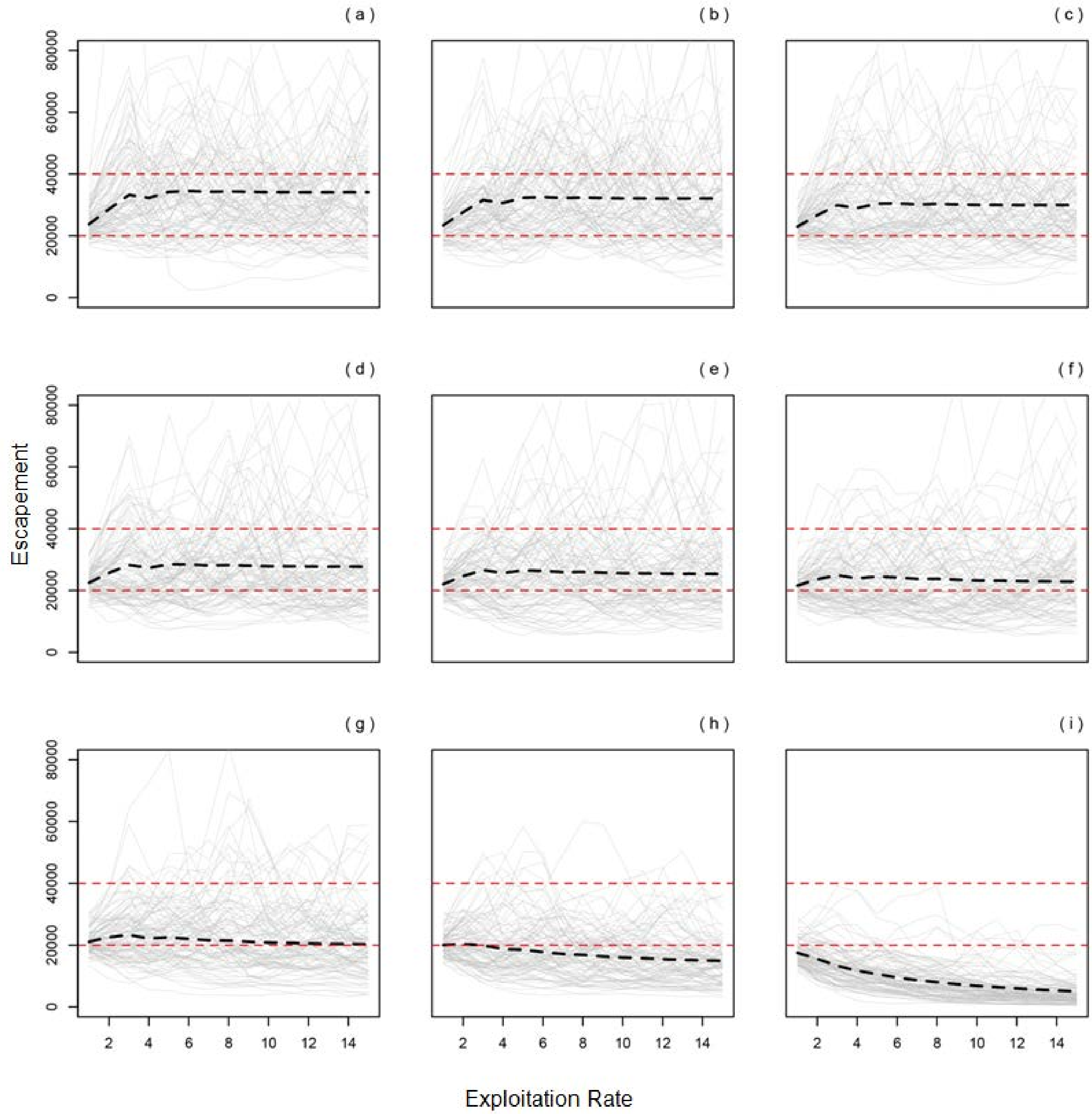

Figure 22. Projected escapement trends under different exploitation rates (ER) with a productivity regime represented by the 1994-2012 period, (i.e., low productivity). Mean escapement trend for 10,000 simulations are plotted at the dashed line, a sample of 100 different escapement trends are potted on each graph. Notice that at exploitation rates above 30% the trend in escapements becomes negative. The dashed horizontal lines represent 20,000 and 40,000 escapement goals. Graph (a) is where ER = 0%; graph (b) is where ER = 5%; graph (c) is where ER = 10%; graph (d) is where ER = 15%; graph (e) is where ER = 20%; graph (f) is where ER = 25%; graph (g) is where ER = 30%; graph (h) is where ER = 40%; graph (i) is where ER = 60%.

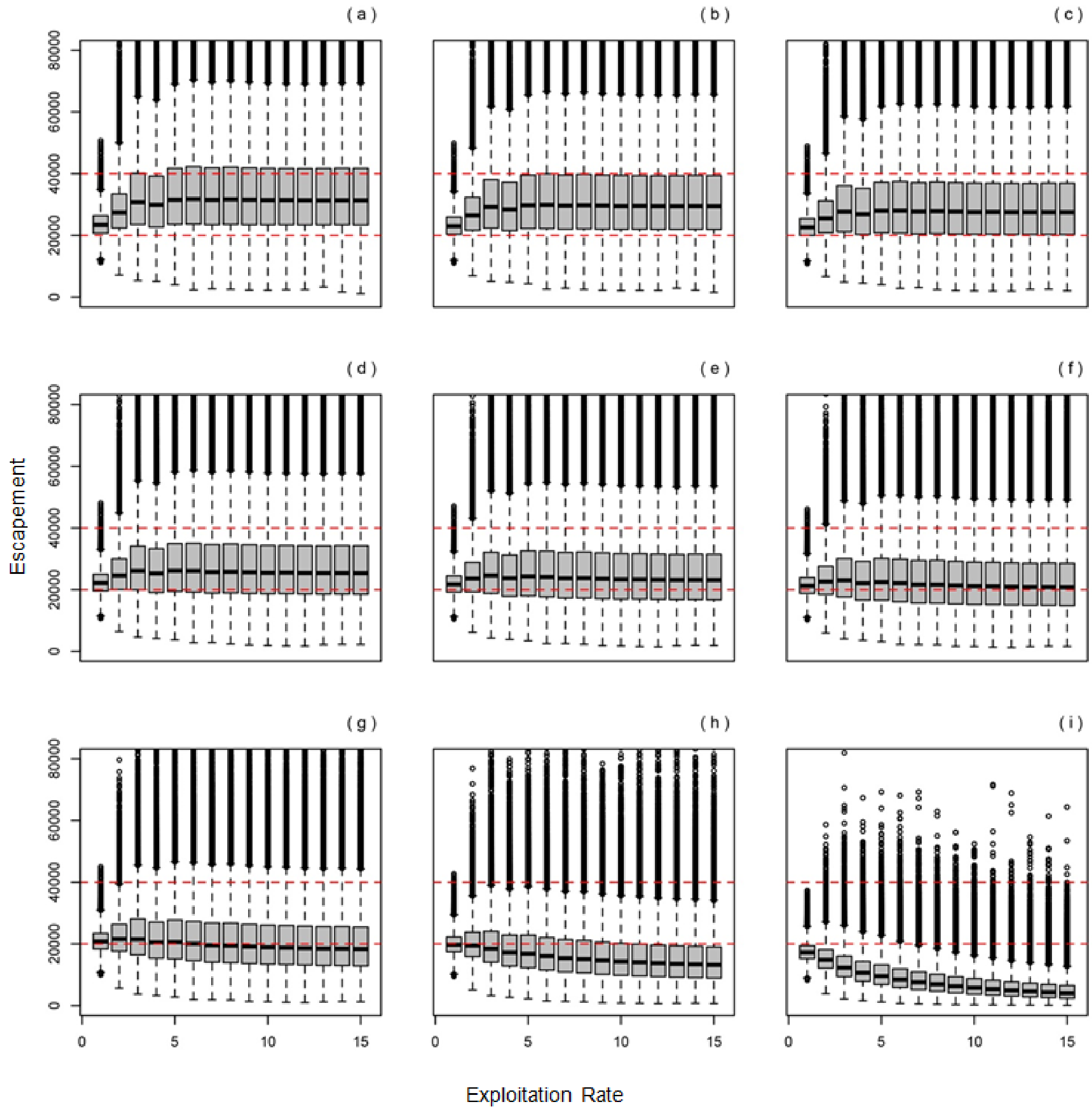

Figure 23. Box plots of projected escapement trends under different exploitation rates (ER) with a productivity regime represented by the 1994-2012 period, (i.e., low productivity). Notice that at exploitation rates above 30% the trend in escapements becomes negative. The dashed horizontal lines represent the IFCRT short-term and long-term recovery objectives of 20,000 and 40,000 wild spawners, respectively. Graph (a) is where ER = 0%; graph (b) is where ER = 5%; graph (c) is where ER = 10%; graph (d) is where ER = 15%; graph (e) is where ER = 20%; graph (f) is where ER = 25%; graph (g) is where ER = 30%; graph (h) is where ER = 40%; graph (i) is where ER = 60%.

10. APPENDICES

10.1. APPENDIX A: CHRONOLOGY OF MANAGEMENT ACTIONS TAKEN BY FISHERIES AND OCEANS CANADA TO CONSERVE INTERIOR FRASER RIVER COHO SALMON

This information was copied from 2006 Conservation Strategy (IFCRT 2006) and then updated with actions current to the 2013 fishing season.

10.1.1. Fraser River Commercial Fisheries

Early 1980s No directed net fisheries for Coho since the early 1980's, although Coho Salmon were harvested incidentally in Sockeye, Pink, and Chum Salmon fisheries.

1980s Commercial net fisheries were closed from approximately the first week of September until the end of October to protect Steelhead trout, Harrison River Chinook Salmon, and Coho Salmon

1997 A minimum mesh size of 158 mm (6 ¼") was instituted in the gill net fishery to minimize Coho Salmon and reduce Steelhead trout by-catches.

1998 Non-retention of Coho Salmon was implemented. Revival boxes were required. Moving window closures (i.e. variable start and end dates of closures in specified sections of the Fraser River mainstem to coincide with the presence of migrating Coho Salmon) from September through October were implemented to avoid interior Fraser River Coho Salmon. Daylight gill net fishing only.

1999 Measures implemented in 1998 were maintained with some modification to the timing of the moving window closure as the Coho Salmon migration period was more precisely defined. In 2005 the window closure below Mission was September 6 to October 7.

2006-2013 Similar management measures continue to be implemented in this fishery today.

10.1.2. Fraser River In-River Coho Salmon Recreational Fishery

Early 1980s The daily limit was reduced from four to two Coho Salmon per day.

1997 Non-retention of Coho Salmon and a 10-day angling closure (October 21-31) was implemented in the mainstem Fraser River, including the mouth, tidal, and non-tidal waters.

1998 A ban on fishing for salmon when Interior Fraser Coho were migrating in the river was implemented, as was a ban on retention of any Coho Salmon throughout the year. Barbless hooks became a coast wide requirement.

2001 Retention of two hatchery Coho Salmon (i.e. those without an adipose fin) was allowed following the Interior Fraser Coho migration window closure (i.e. the period with no fishing for salmon). Night fishing for salmon was prohibited in the Fraser River from September 1 to December 31. Retention of wild Coho Salmon continued to be prohibited at all times.

2002-2005 Retention of two hatchery (adipose fin absent) Coho Salmon per day was allowed from mid-October to December 31. The ban on salmon fishing during the Interior Fraser Coho migration period (September to mid-October) was continued during even numbered years (i.e. when Pink Salmon were not present). In 2003 and 2005, fishing for Pink Salmon was allowed during the Interior Fraser Coho migration window; however, all fishing with bait was prohibited.). Fraser River tidal and non-tidal waters downstream of Alexandra Bridge (Area 29) daylight only selective hatchery marked Coho Salmon fishery were permitted during October.

2006-2013 Retention of 2 hatchery marked Coho Salmon per day was allowed from early-mid October to December 31. Non-retention of wild Coho Salmon is maintained. Coho Salmon migration window closure from early September to early-mid October in tidal and non-tidal Fraser River downstream of Alexandra Bridge. The use of bait is prohibited during Coho Salmon window closures.

10.1.3. Fraser River First Nations Fishery

1989-1990 Fishing times were restricted in October from three to one day/week from Mission to North Bend to reduce Steelhead trout catch.

1992 Coho Salmon allocations were established for the first time; 6,500 fish for native bands below Sawmill Creek. Allocations were not set for bands above Sawmill Creek. Below Sawmill Creek, the fishery was closed from mid-August to mid-October and opened for restricted times beginning in late October, for one week below the Port Mann Bridge and for three weeks from the Port Mann Bridge to Sawmill Creek.

1993 Coho Salmon allocations for bands below Sawmill Creek were 17,000 and approximately 10,000 Coho Salmon for bands above Sawmill Creek. As in 1992, fishing times were restricted in order to meet allocations.

1994 Coho Salmon allocations for bands below Sawmill Creek were 2,500 and 3,800 for bands above Sawmill Creek. The fishery below Sawmill Creek was closed for three weeks in October and opened for restricted periods in late October and early November.

1995 Coho Salmon allocations for bands below Sawmill Creek were 2,500 and 3,500 for bands above Sawmill Creek. The fishery below Sawmill Creek was closed for five weeks (six weeks for the Musqueam and Tsawwassen area) from mid/late September to mid/late October, but was opened for restricted periods for three weeks beginning in late October and then closed.

1996 No Coho Salmon allocation was established for bands below Sawmill Creek. The combined allocation for all bands above Sawmill Creek was 395. The fishery below Sawmill Creek was closed from early September until late October, and opened for restricted periods each week in November. Above Sawmill Creek, the fishery was closed from Sawmill Creek to Deadman Creek after September 28. In addition, a number of Shuswap bands voluntarily agreed to zero Coho Salmon allocations.

1997-1998 No fishing for salmon when Interior Fraser Coho were migrating through the river was authorized. Voluntary non-retention of all Coho Salmon was requested. The use of selective fishing techniques was encouraged. Some opportunities for Coho Salmon harvest were provided in those terminal areas with hatchery surpluses.

1999-2005 First Nations directed fishing for Coho Salmon has been restricted. Commercial harvest of Pink Salmon has been authorized, by selective means only (beach seine, etc.), in the Fraser River during the Interior Fraser Coho migration period with the requirement that wild Coho Salmon are to be released. First Nations fishers are authorized to retain Coho Salmon mortalities during gill net and set net fisheries before and after the migration window for Interior Fraser Coho has passed. All live wild Coho Salmon are to be released unharmed.

2006-2013 First Nations directed fishing for Coho Salmon has been restricted. During non-Pink Salmon years the Coho Salmon migration window closure is in place from early September to early mid-October with the exception of 2007 which is noted below.

2007 First Nations were authorized 8” mesh drift fishery targeting Chinook, Pink, Chum and hatchery marked Coho Salmon for 6 days during the window closure to test the selectivity of 8” mesh on Coho. This was not authorized in subsequent years.

10.1.4. South Coast Net Fisheries – Johnstone Strait (Area 12/13) & Juan de Fuca Strait (Area 20)

1977 Permanent area closures of Parson Bay, Goletas Channel, and Mainland Inlets (except for Pink Salmon surplus) in Johnstone Strait (Area 12/13), and gill net mesh size restriction.

1978 Permanent closure of Loughborough Inlet and Phillips Arm.

1979 Reduced fishing season (initial fishery openings delayed until July). Permanent closure of Bute Inlet (except for Chum Salmon surplus fisheries). A coast-wide (except Area 20) gear restriction limiting the maximum seine depth to 52m.

1981 Area 12/13 closed to all commercial fishing April 14 – June 17. Permanent closure of Deepwater Bay. Area closure known as the “Ribbon Boundary corridor” from Hanson Island (Area 12) to Discovery Passage (Area 13). Juan de Fuca seine fishery limited to a minimum 100 mm mesh size.

1982 Permanent closures of lower Knights Inlet and Growler Cove. Seine net gear restricted to so-called “fall bunts” implemented earlier in season.

1983 Reduced fishing times (number of days) in Areas 12 and 13 under the “Clockwork Chum Strategy”.

1985-1986 Compliance boundary set at the 30 fathom contour in the Area 20 seine fishery. By-catch monitoring program ran from 1986-1990 in Areas 12 and 13.

1987 By-catch monitoring program ran from 1987-1990 in Area 20.

1989 Further reduction in fishing time in Areas 12 and 13.

1994 Reduced fishing times in Area 20. Coho Salmon catch ceiling established with a monitoring program. Gear restrictions in Areas 12 and 13. Voluntary non-retention of Coho Salmon.

1995 Reduced fishing times in Area 20, no gill net fishing. Coho Salmon catch ceiling established with a monitoring program. Reduced fishing areas and gear restrictions in Areas 12 and 13. Voluntary non-retention of Coho Salmon.

1996 Reduced fishing times in Area 20. Reduced fishing areas and gear restrictions in Areas 12 and 13. Voluntary non-retention of Coho Salmon in the seine fishery.

1997 In-season monitoring and closures in Coho Salmon sensitive areas. Mandatory non-retention of Coho Salmon in all seine fisheries. Implementation of Coho Salmon mortality ceilings for each net fishery. “Yellow Line/Red Line” fishing zone strategy for managing Coho Salmon mortality rates. Sorting and live release of Coho Salmon in seine fisheries in Juan de Fuca and Johnstone straits. Voluntary non-retention of Coho Salmon for gill net fisheries.

1998 No fishing for salmon in red zones (i.e. areas where Coho Salmon were prevalent). Mandatory non-retention of Coho Salmon in all fisheries. Functioning revival boxes required on all vessels actively fishing. Gill net length and set time shortened in some fisheries to reduce Coho Salmon encounters and mortalities in yellow zones. Daylight only fisheries implemented. Seine net fishers required to brail and sort catch with Coho Salmon released back to the water with least possible harm.

1999 Per the pre-season fishing plan, the Chum assessment fishery in the third week of September was cancelled to protect returning Coho Salmon. Non-retention and non-possession of all Coho Salmon and mandatory revival tanks were license requirements. All Coho Salmon were to be released to the water with the least possible harm. Specific areas and times where Coho Salmon were expected to be present were closed.

2000-2001 No fishing for Coho Salmon and no possession of Coho Salmon in all Special Management Zones (i.e. those areas and times where or when Thompson River Coho Salmon or other Coho Salmon populations of concern are prevalent). Fishing for other salmon species within Special Management Zones has been permitted in some areas. Special Management Zones include: West Coast of Vancouver Island (Areas 23 to 27 and 123 to 127) from May 1 to September 30; Johnstone Strait and the mainland inlets (Areas 11-13) from May 1 to September 30; Strait of Georgia (Areas 14-18 and Area 28) May 1 to September 20; Southern Vancouver Island

(Areas 19-21 and 121) May 1 to September 30; and vicinity of Fraser River (Area 29) August 1 to October 15. All Coho Salmon were to be released to the water with the least possible harm. Mandatory brailing and wet sorting of seine catch was required in some areas. Revival tanks were required.

2002-2013 Conservation measures for the protection of Interior Fraser Coho were similar to those implemented in 2001.

10.1.5. South Coast Troll

The west coast Vancouver Island (WCVI) troll fishery has undergone major changes to address Coho Salmon conservation concerns. In summary, the WCVI troll fishery has gone from a 1.75M Coho Salmon catch in 1985, to 1.3M in 1993, to 1.0M in 1996, to no troll fishery in 1997. Management actions since 1990 include:

1990-1993 The “red line/green line” management strategy was implemented to extend the season and minimize “shaker” mortality. Selected conservation areas were closed. In-season catch monitoring via the hail-in program was started. Non-retention of Coho Salmon after the catch ceiling was reached was required.

1994 Continued the red line/green line management strategy to extend the season and minimize shaker mortality. Selected conservation areas were closed. Monitored Coho Salmon catch via the hail-in program. Reduced fishing time. Non-retention of Coho Salmon after catch ceiling was reached was required.

1995 Selected conservation areas were closed. Time and area closures were implemented to reduce exploitation rate. Monitored in-season catches via the hail-in program. Reduced fishing times. Non-retention of Coho Salmon after catch ceiling was reached was required.

1996 Closure of Chinook Salmon sensitive areas off WCVI to address conservation concerns for WCVI Chinook Salmon stocks. This action also minimized access by the fishery to other salmon species including Coho Salmon. Area closures used to reduce exploitation rate on Coho Salmon. In-season catch monitoring program via a hail-in program. Managers used data to conduct in-season alterations to time and area openings. Non-retention of Coho Salmon after catch ceiling reached was required.

1997 No directed commercial fishery for Coho Salmon in southern B.C. Non-retention and non-possession of Coho Salmon in the WCVI troll fishery. Closure of Coho Salmon sensitive areas off WCVI to address conservation concerns for southern BC Coho Salmon. This action minimized access by the fishery to other salmon species. In-season catch monitoring program along with a hail-in program to record catches. Managers used data to conduct in-season changes to time and area openings to minimize Coho Salmon by-catch.

1998-1999 No fishing for salmon in red zones. Non-retention of all Coho Salmon. A functioning revival box was required on all boats actively fishing. All Coho Salmon were to be released to the water with the least possible harm. Barbless hooks became a requirement.

2000-2001 No fishing for Coho Salmon and no possession of Coho Salmon in all Special Management Zones (i.e. those areas and times where or when Thompson River Coho or other Coho Salmon stocks of concern are prevalent). Fishing for other salmon species within Special Management Zones was permitted in some areas. Special Management Zones included: West Coast of Vancouver Island (Areas 23 to 27 and 123 to 127) from May 1 to September 30; Johnstone Strait and the mainland inlets (Areas 11-13) from May 1 to September 30; Strait of Georgia (Areas 14-18 and Area 28) May 1 to September 20; Southern Vancouver Island (Areas 19-21 and 121) May 1 to September 30; and vicinity of Fraser River (Area 29) August 1 to October 15. All Coho Salmon were to be released to the water with the least possible harm. Revival tanks were required.

2002-2005 Conservation measures for the protection of Interior Fraser Coho were similar to those implemented in 2001. In 2005 retention of marked Coho Salmon was allowed in some commercial South Coast fisheries (e.g. WCVI Chinook fisheries after mid-Sept).

2006-2013 Similar management actions have been in place since 2005 with the addition of a plug fishery in August for Chinook salmon with non-retention restrictions for Coho Salmon.

10.1.6. Marine Recreational Fishery

1995 Reduction of the daily catch and possession limit in Juan de Fuca Strait to two and four Coho Salmon from four and eight Coho Salmon.

1997 Effective July 2, reduction of the daily catch and possession limit for Coho Salmon to two and four fish from four and eight on the west coast of Vancouver Island from Port Renfrew to Cape Scott. Effective July 2, the daily bag and possession limits in the Strait of Georgia remained at the previously reduced levels of two and four Coho Salmon. Effective July 2, existing area closures in the majority of Vancouver Island, Sunshine Coast, and southern mainland stream areas were re-instituted. In-season area closures were expanded in a number of areas to increase the amount of protected area for Coho Salmon.

1998 No fishing for Coho Salmon in red zones. Non-retention of Coho Salmon in all South Coast fishery areas was required. Barbless hooks required when salmon fishing. The only Coho Salmon retention fisheries allowed were in terminal areas where hatchery fish were present (adipose fin clipped only).

2000 Some expansion of areas open to selective fishing for hatchery marked fish. Non-retention of wild Coho Salmon maintained.

2001 Some retention of wild Coho Salmon was allowed in areas where local populations were in abundance and where Interior Fraser Coho were not present (i.e. north end of Johnstone Strait and some WCVI inlets).

2002 Selective hatchery marked Coho Salmon fishing opportunities were expanded from those provided in 2001. Selective hatchery mark Coho Salmon fisheries in the recreational fishery were allowed in marine areas targeting on Coho Salmon which have a hatchery mark (i.e. adipose fin absent). These fisheries also occurred in some terminal areas adjacent to hatchery facilities where there was a surplus of Coho Salmon. These measures were subject to in-season changes if additional conservation concerns developed. Effective August 1 the retention of two hatchery marked Coho Salmon was permitted in Queen Charlotte Sound and Strait (Area 11 and 12), Johnstone Strait and Strait of Georgia (Areas 23-19, 28 and 29 excluding the tidal waters of the Fraser River, the West Coast Vancouver Island (Areas 23-27 and 123-127), and Juan de Fuca Strait (Area 20

2003-2005 Selective hatchery mark Coho Salmon fisheries became more prevalent. They expanded to include most of DFO's South Coast recreational fishing areas.

2006-2013 Management actions initiated in 2002 remain in place today with some modifications that allow for the retention of hatchery and wild Coho Salmon in WCVI inlets inside the surfline.