Cohort Analyses and New Developments for Coded Wire Tag Data of Atnarko River Chinook Salmon

L.A. Vélez-Espino, J. Willis, C.K. Parken, and G. Brown

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, BC
V9T 6N7

2011

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2958

Fisheries and Oceans | Pêches et Océans

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of the Department of Fisheries and Oceans, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 1426 - 1550 were issued as Department of Fisheries and the Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out-of-stock reports will be supplied for a fee by commercial agents.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques ques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques du ministère des Pêches et des Océans, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications complètes. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la revue *Résumés des sciences aquatiques et halieutiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les numéros 1 à 900 de cette série ont été publiés à titre de manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Les rapports manuscrits sont produits a l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés seront fournis contre rétribution par des agents commerciaux.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 2958

2011

COHORT ANALYSES AND NEW DEVELOPMENTS FOR CODED WIRE TAG DATA OF ATNARKO RIVER CHINOOK SALMON

by

L.A. Vélez-Espino, J. Willis, C.K. Parken, and G. Brown

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
3190 Hammond Bay Road
Nanaimo, BC
V9T 6N7

Cat. No. Fs 97-4/2958E ISSN 0706-6473

Correct citation for this publication:

Vélez-Espino, L.A., Willis, J., Parken, C.K., and Brown, G. 2011. Cohort analyses and new developments for coded wire tag data of Atnarko River Chinook salmon. Can. Manuscr. Rep. Fish. Aquat. Sci. 2958: xiii + 68 p.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

Vélez-Espino, L.A., Willis, J., Parken, C.K., and Brown, G. 2011. Cohort analyses and new developments for coded wire tag data of Atnarko River Chinook salmon. Can. Manuscr. Rep. Fish. Aquat. Sci. 2958: xiii + 68 p.

The Coded Wire Tag (CWT) workgroup of the Pacific Salmon Commission (PSC) recently identified that major Chinook salmon (*Oncorhynchus tshawytscha*) production regions and life histories are poorly represented by CWT indicator stocks currently used for assessments by the PSC Chinook Technical Committee (CTC). One of these major production areas without a CWT indicator stock is the central coast of British Columbia, where the abundance of Chinook salmon spawners is dominated by returns to the Atnarko River in the Bella Coola River watershed. Although the Bella Coola River watershed has had the most intensive assessment in central British Columbia, including the most thorough escapement assessment in the region, and in spite of Atnarko Chinook being CWTed since 1976, significant issues have prevented the inclusion of this population as a CWT indicator stock in PSC assessments: (i) a need for validation of the quality of estimates of total escapement; (ii) the need for adequate sampling allowing estimation of freshwater CWT recoveries; (iii) data coordination reporting problems; and, (iv) limitations of funds to conduct robust and effective sampling and analysis. The main objectives of this investigation were to compile, evaluate, and improve the Atnarko Chinook CWT recovery data from freshwater fisheries and escapement, and then use these data for cohort analyses. Cohort analysis is the reconstruction of the exploitation and spawning history of a stock using CWT release and recovery data to estimate key population statistics, such as survival, maturation, and exploitation rates. The successful completion of cohort analyses for this stock contributes to the goal of incorporating Atnarko Chinook into future CTC assessments to better represent life histories and exploitation patterns of central British Columbia Chinook salmon populations.

RÉSUMÉ

Vélez-Espino, L.A., Willis, J., Parken, C.K., and Brown, G. 2011. Cohort analyses and new developments for coded wire tag data of Atnarko River Chinook salmon. Can. Manuscr. Rep. Fish. Aquat. Sci. 2958: xiii + 68 p.

Le groupe de travail sur les micromarques magnétisées codées de la Commission du saumon du Pacifique (CSP) a récemment établi que les stocks indicateurs micromarqués de saumon quinnat (*Oncorhynchus tshawytscha*) utilisés actuellement par le Comité technique du saumon quinnat (CTQ) de la CSP représentaient mal les principales zones de production et les cycles vitaux de l'espèce. La côte centrale de la Colombie-Britannique, où les retours dans la rivière Atnarko, située dans le bassin versant de la rivière Bella Coola, constituent la composante dominante des géniteurs, est l'une de ces principales zones de production sans stock indicateur micromarqué. Bien que le bassin versant de la rivière Bella Coola ait été l'objet de l'évaluation la plus exhaustive dans le secteur central de la province, y compris l'évaluation la plus détaillée de l'échappée dans la région, et malgré le fait que le saumon quinnat de l'Atnarko soit micromarqué depuis 1976, des problèmes majeurs ont empêché l'inclusion de cette population comme stock indicateur micromarqué dans les évaluations de la CSP, notamment : (i) le besoin de valider la qualité des estimations de l'échappée totale; (ii) le besoin d'un échantillonnage adéquat permettant d'estimer le nombre de micromarques récupérées en eau douce; (iii) les problèmes de coordination des rapports de données et (iv) les limites imposées par le manque de fonds pour effectuer un échantillonnage et une analyse robustes et efficaces. Les principaux objectifs de la présente étude étaient de compiler, d'évaluer et d'améliorer les données sur les micromarques récupérées sur des saumons quinnats de l'Atnarko capturés en eau douce et des géniteurs, puis d'utiliser ces données dans des analyses par cohorte. L'analyse par cohorte permet de reconstituer les taux d'exploitation et l'historique de la fraie d'un stock en utilisant les données de pose et de récupération de micromarques métalliques codées pour estimer des variables clés d'une population, comme le taux de survie, le niveau de maturation et les taux d'exploitation. L'exécution réussie d'analyses par cohorte pour ce stock contribue au but d'inclure le saumon quinnat de l'Atnarko dans les évaluations futures faites par le CTQ de sorte à mieux représenter les cycles vitaux et les patrons d'exploitation des populations de quinnats de la côte centrale de la Colombie-Britannique.

1. INTRODUCTION

1.1. The importance of Atnarko River coded wire tagged Chinook salmon

The Chinook salmon (*Oncorhynchus tshawytscha*) population that has had the most intensive assessment in central British Columbia (BC) spawns in the Bella Coola River watershed (Riddell 2004). Distribution of Chinook salmon in the Bella Coola River watershed is mainly concentrated in the Atnarko River with some Chinook spawning and rearing in the Talchako River and tributaries in the Lower Bella Coola River (BCWCS 2007). The abundance of Chinook salmon spawners in central BC are dominated by returns to the Atnarko River, and returns to the Bella Coola system are frequently five to ten times the next largest Chinook population in this area (Riddell 2004). Bella Coola, BC is the site of Snootli Creek Hatchery, which is a major Chinook hatchery that has released Chinook fry and smolts with implanted coded wire tags (CWT) since 1976, providing a long record for hatchery assessments and fishery management. The hatchery and local management staff have put substantial effort toward developing the necessary recovery programs and estimation procedures, but the Atnarko program has not yet been fully developed as an exploitation rate or escapement[1] indicator Chinook stock in assessments conducted by the Pacific Salmon Commission (PSC).

A recent report of the CWT workgroup of the PSC identified there is insufficient CWT indicator stock coverage of production regions or stock aggregates in BC (PSC 2008). It was recognized that major Chinook salmon production areas and life histories are poorly represented by CWT indicator stocks currently used for assessments by the PSC Chinook Technical Committee (CTC). Presently, there is no appropriate indicator of the biological and fishery characteristics of Chinook salmon stocks entering the central coast area of BC. In 2008, the CWT workgroup of the PSC recommended agencies to evaluate their escapement estimation and sampling programs where CWTed Chinook are present on the spawning grounds (PSC 2008). Although Atnarko Chinook have been CWTed for many years in the Snootli Creek Hatchery, and the most thorough Chinook escapement assessments in central BC come from the Bella Coola/Atnarko system (Riddell 2004), some issues have been identified as limiting the quality of information: a need for validation of the quality of estimates of total escapement, the need for adequate sampling to estimate freshwater CWT recoveries, data coordination reporting problems, and limitations of funds to conduct robust and effective sampling and analysis (PSC 2008). Accordingly, Fisheries and Oceans Canada initiated in 2009 a CWT Improvement Program, under the 2008 Pacific Salmon Treaty Agreement, that incorporates a five-year mark-recapture program in the Atnarko River with the purpose of improving escapement estimates for early summer Chinook (see also Vélez-Espino et al. 2010).

Chinook salmon CWT indicators nearest to the Atnarko are the Kitsumkalum in north BC and Quinsam in the east coast of Vancouver Island. Although Chilliwack in south BC in mainland is geographically close, the aquatic distance separating it from the

[1] Atnarko Chinook is, however, identified in Attachment IV of Chapter 3 of the 2008 Agreement (Pacific Salmon Treaty) as an indicator stock with escapement management objectives for the purposes of Individual Stock Based Management fisheries in British Columbia.

Atnarko is much greater than the aquatic distance between the Atnarko and either Kitsumkalum or Quinsam. While the northern BC stock group in the PSC Chinook Model[2] is represented by the Kitsumkalum, the central BC group (currently represented by Wannock, Chuckwalla, and Dean Rivers), does not have an exploitation rate indicator. Differences in life history, ecology, and molecular genetics between Kitsumkalum Chinook and Atnarko Chinook have placed these two stocks in separate conservation units in Canada, with Atnarko Chinook as the primary contributor to the Bella Coola-Dean Conservation Unit (Holtby and Ciruna 2007). Although the majority of Chinook entering the Bella Coola spawn in the Atnarko, there is also a small group of lower Bella Coola tributary spawners which are enumerated annually using stream walks. These Bella Coola spawners are believed to make up a very small component of the overall system (Personal communication; Julian Sturhahn, Fisheries and Oceans Canada Campbell River, BC). In terms of life history, Atnarko Chinook exhibits a life history type that is predominantly ocean type (i.e., sub-yearling ocean migrants; Pestal 2004) whereas Kitsumkalum Chinook is mostly stream type (i.e., yearling ocean migrants; McNicol 1999).

The present investigation builds on the recommendations of the PSC CWT expert panel and CWT workgroup by analyzing existing Atnarko Chinook CWT data, filling information gaps in freshwater recoveries, and conducting cohort analyses. Since CWT recoveries of Atnarko Chinook are more numerous than other PSC indicator stocks in the region, and its life history and exploitation patterns differ from those of neighbouring indicator stocks, this task is particularly important in order to include Atnarko Chinook as a new exploitation rate indicator stock in future PSC assessments.

1.2 Hatchery contribution

Atnarko hatchery Chinook production has averaged around 2 million fish annually with 150,000 of released fry having been implanted with CWTs and marked with adipose fin clips (AFC). This level of enhancement has continued since the mid 1980's, usually splitting the release of juvenile fish between the upper and lower Atnarko River in an attempt to cover potential differences in outmigration timing between the areas. In addition, release timings are structured with sub-yearling and yearling releases to match the various life history strategies present. Direct hatchery contributions are measured and compared using several methods. The annual Chinook deadpitch program is believed to be the least biased of the methods, and historical AFC mark presence data suggest an average hatchery contribution of approximately 40% of the spawning runs (Personal communication; Julian Sturhahn, Fisheries and Oceans Canada Campbell River, BC). In some years, an estimated 30-40% of the total Chinook escapement to the Bella Coola watershed is of hatchery origin (Hilland and Lehman 2005). For comparison, hatchery

[2] The primary uses of the PSC Chinook Model are estimating abundance indices (AIs, relative abundance compared to 1979-1982) for implementation of Aggregate Abundance Based Management (AABM) fishing regimes, providing data for models used in domestic fishery planning processes (e.g. Pacific Fishery Management Council, ESA recovery planning), and providing data for pre-season Individual Stock Based Management (ISBM) fisheries.

contribution to the total escapement in the Kitsumkalum has averaged 2.5% since 1984, with a maximum of 7.7% in the 1997 return (Riddell 2004).

1.3 Study Area

The Atnarko River is a tributary of the Bella Coola River and is situated in Pacific Fisheries Management Area 8 on the central coast of B.C. (Figures 1 and 2). The Atnarko River drains a 2,440 km^2 watershed, merging with the Talchako River to form the Bella Coola River. With the exception of Charlotte Lake and the headwaters of the Hotnarko River, the Atnarko and its tributaries (Figure 3) are situated within the boundaries of Tweedsmuir Provincial Park. The Atnarko can be divided into three river segments with specific biotic and abiotic attributes. The upper segment has many sections with deep and large holding areas that constitute high quality spawning areas. Overall the spawning habitat is excellent with the exception of the lower part of the upper section where the river gradient decreases, resulting in very slow water velocities and virtually no spawning habitat. The middle segment is characterized by sections with larger substrate, boulders, and increased gradient drops. Higher water velocities result in a generally lower quality spawning habitat. Holding in this section is limited and spawning is generally sporadic. The lower segment is characterized by braided sections and dominated by high quality spawning habitat in its middle and lower sections. The upper part of this section does have some areas with large boulders and large substrate (due to increases in the river gradient), and thus limited areas to spawn.

The fisheries that currently target Chinook salmon in Area 8 (Figure 1) include (1) Bella Coola Commercial Gillnet Fisheries, (2) Bella Coola River First Nations net fishery (FNFF), and (3) Bella Coola/Atnarko in-river sport fishery (BCWCS 2007). The Burke Channel, North Bentinck Arm and Labouchere Channel are the main gillnet fishing areas that target Atnarko Chinook. Typically the earliest commercial fishery in Area 8 is the Chinook gillnet fishery in the Bella Coola Gillnet Area. This fishery begins in mid-May or early June, before other species are present in large numbers. Outside of the Bella Coola Gillnet Area, fishermen are requested to release all Chinook (DFO 2002). Since the 1980s the commercial Chinook fishery in Area 8 has not operated during years of low stock abundance (DFO 1986). A fleet of approximately 40 vessels using large mesh gillnets is normal for recent years. The Nuxalk Band harvests Chinook from the Upper and Lower Bella Coola River (DFO 2002). The Ulkatcho Band also fishes the Atnarko River for Chinook (Anon 2001) and the Upper Bella Coola River (DFO 2002). The in-river sport fishery catch is somewhat constrained by water conditions and little river access.

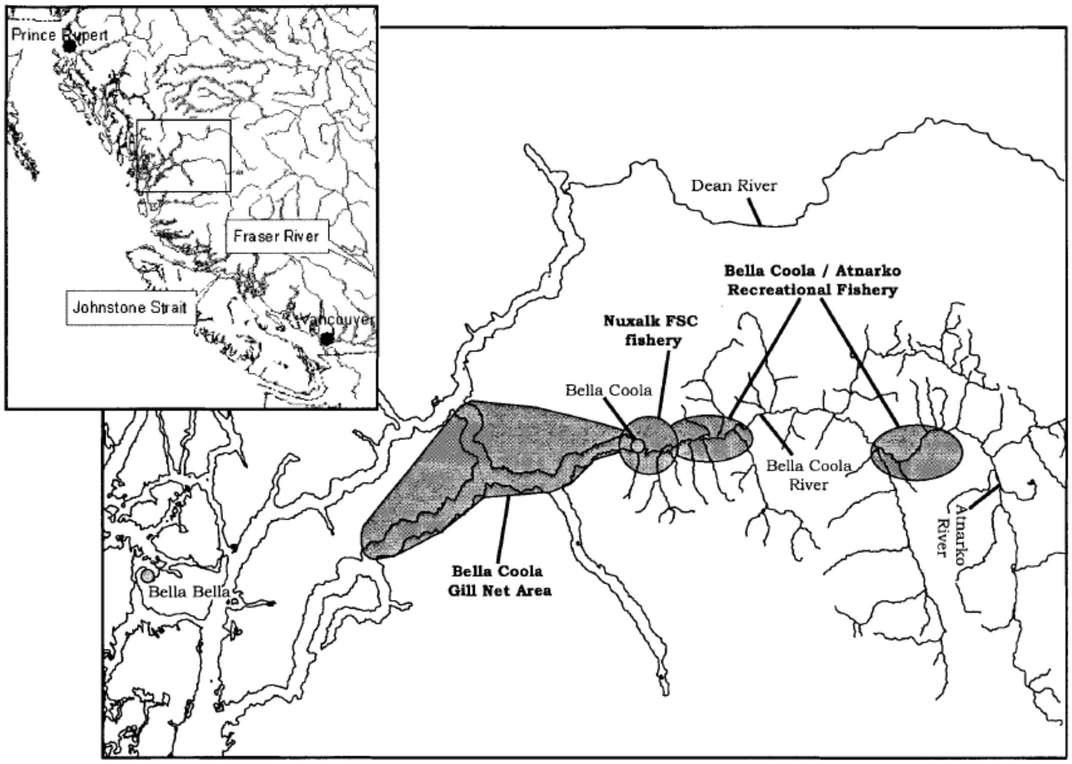


Figure 1. Map of British Columbia showing location of the Bella Coola fishing areas and the Atnarko River (based on a map provided by Kay Kennes, Fisheries and Oceans Canada, Vancouver).

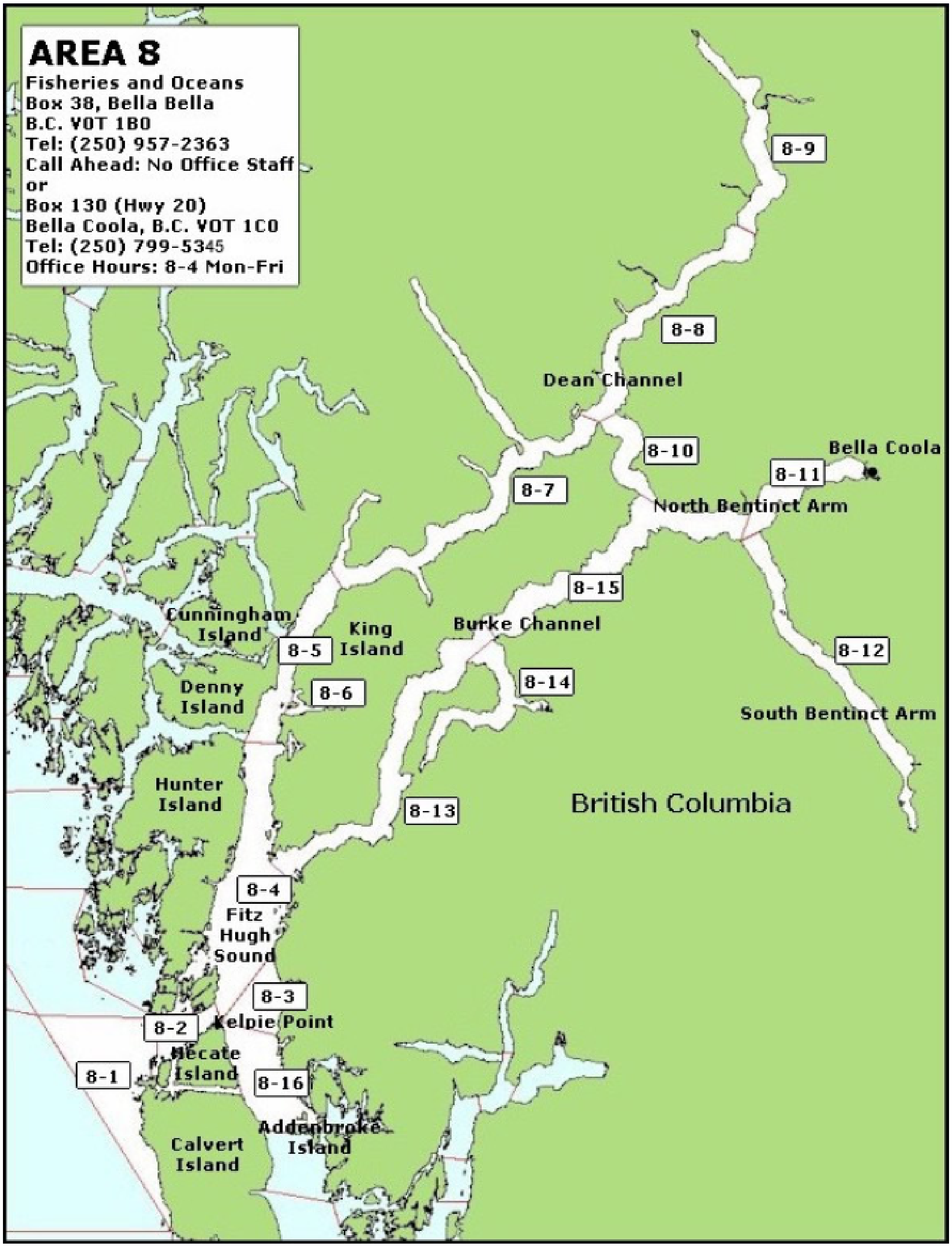


Figure 2. Map of Area 8 (DFO website <http://www.pac.dfo-mpo.gc.ca/ops/fm/Areas/area_08_e.htm>).

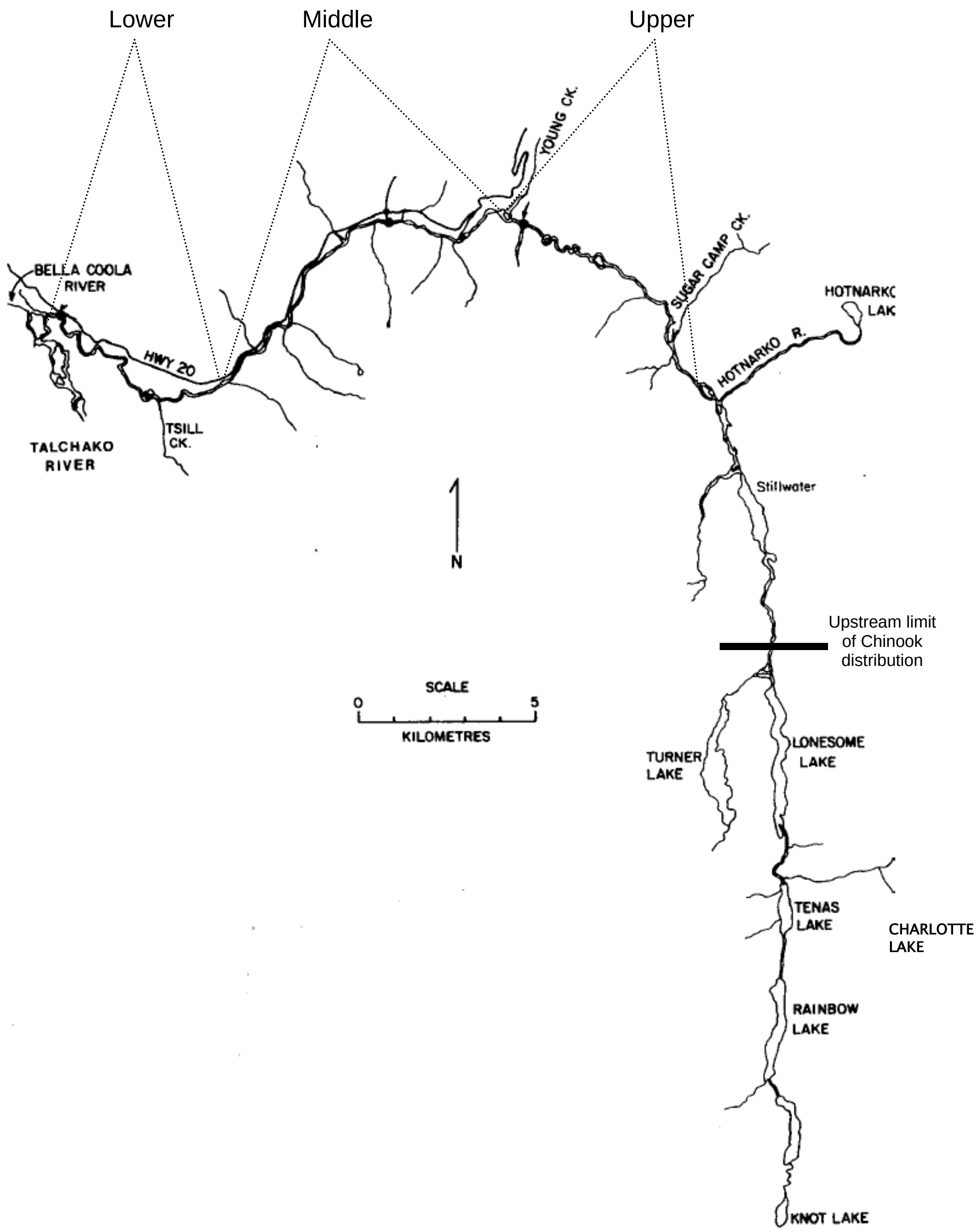


Figure 3. The Atnarko River drainage and spatial strata (river segments) considered in field surveys, including mark-recapture studies. At least 95% of Atnarko Chinook spawn below the upstream boundary of the upper river section. The upstream limit of Chinook salmon distribution is also shown.

1.4. Objectives

The main objectives of this investigation are the compilation, evaluation, and improvement of Atnarko Chinook CWT recovery data from freshwater fisheries and escapement, and the use of this data in the execution of cohort analyses (Box 1). The successful completion of cohort analyses (also known as Virtual Population Analysis; Lassen and Medley 2001) for this stock fits within the goal of incorporating Atnarko Chinook as a CWT indicator stock in future CTC assessments (including those derived from the PSC Chinook model) to better represent central BC Chinook salmon production areas and life histories. Several steps were taken to address missing freshwater CWT recovery data, including: (i) filtering CWT recoveries by release type and site; (ii) validating and calibrating escapement estimates from a time period exhibiting a consistent methodology; (iii) developing methods to generate catch sampling fractions for First Nations and recreational fisheries; and, (iv) developing methods to generate CWT pseudo-recoveries from recent years for the commercial net fishery in the Bella Coola River and for the escapement for brood years 1976-1978 contributing to the base period 1979-1982. In addition to Snootli Creek Hatchery historical records, two data bases were examined to accomplish these objectives: the Regional Mark Information System (RMIS; http://www.rmpc.org/) and the Mark Recovery Program (MRP; Fisheries and Oceans Canada). The completion of these tasks made possible cohort analyses at two levels: (i) towards the implementation of annual exploitation rate analyses; and, (ii) towards the generation of data for the base period (1979-1982) specified in the Pacific Salmon Treaty (PST).

Box 1. Cohort analysis of PST Chinook salmon (background information)

Cohort analysis (or virtual population analysis) of PST Chinook stocks is the reconstruction of the exploitation and spawning history of a given stock and brood year using CWT release and recovery data (PSC 1988). A cohort, in this context, is the total production which results from the escapement of a single year class from a particular group of fish. The procedure produces a variety of statistics, including total exploitation rates, age and fishery specific exploitation rates, maturation rates, pre-age 2 recruitment survival indices, and annual distribution of fishery-related mortalities. Estimates of age and fishery-specific exploitation and maturation rates from the cohort analysis are combined with data on catches, escapements, non-retention, and enhancement to complete the annual calibration of the PSC Chinook Model. The calibration procedure estimates pre-age 2 recruitment survivals for the stocks included in the model.

In a cohort analysis, data are analyzed through a backwards-stepping procedure, beginning with the oldest age class. Escapement, an estimate of pre-spawning mortality (when appropriate), and the terminal catch (including associated incidental mortality) are added to produce a mature run size for that age class. The ocean catches of that age class, associated incidental mortalities, and the cohort size of the next older age class are added to compute the size of the population immediately prior to fishing. This sum is then divided by the survival rate (1 - natural mortality) to give the cohort size for that age class. The backwards cohort run reconstruction procedure is continued until all catches have been accounted for through age 1. The resulting age 1 cohort is the estimated total stock which recruited from a particular release. Therefore, the cohort size at any age will include all mortalities which occur in that year plus the number of fish alive at the end of the fishing year. When age i = MaxAge, then the cohort size at age i+1 = 0. The cohort size at age is increased by the mortalities due to non fishing causes ("natural" mortality) after all fishing mortalities have been included.

The primary assumptions of the cohort analysis are:

1) CWT recovery data are obtained in a consistent manner from year to year or can be adjusted to make them comparable. Many of the analyses rely upon indices that are computed as the ratio of a statistic in a particular year to the value associated with a base period. Use of ratios may reduce or eliminate the effect of data biases that are consistent from year to year.
2) For ocean age-2 and older fish, natural mortality varies by age but is constant across years. Natural mortality rates applied by ocean age are: age-2, 40%; age-3, 30%; age-4, 20%; and age-5 and older, 10% (i.e., after fishing mortality and maturation of the age-4 cohort, 10% of the remaining immature fish die due to natural sources before becoming age-5 fish and before the commencement of fishing the next year).
3) All stocks within a fishery have the same size distribution for each age and the size distribution at age is constant among years.
4) The spatial and temporal catch distribution of sublegal-size fish of a given age from a stock is the same as legal-size fish of a given age of that stock.
5) Incidental mortality rates per encounter are constant between years. The rates vary by fish size (legal or sublegal) and fishery and are those published in PSC (1997) for troll and sport fisheries.
6) The procedures for estimating the mortality of CWT fish of legal size during periods of Chinook non-retention (CNR) assume that the stock distribution in any year remains unchanged from the period of legal catch retention in the same year. However, gear and/or area restrictions during CNR fisheries are believed to reduce the number of encounters of legal-size fish. To account for this, the numbers of legal encounters during CNR fisheries are adjusted by a selectivity factor.
7) Maturation rates for brood years in which all ages have not matured (incomplete broods) are equal to the average of completed brood years. Maturation rates are stock specific.
8) Recoveries of age-4 (age-5 for spring stocks) and older Chinook salmon in ocean net fisheries are assumed to be mature fish (ocean terminal catches).
9) In addition, when using the fishery indices as a measure of the change in fishery harvest rates between years, the temporal and spatial distribution of stocks in and among fisheries and years is assumed to be stable.

2.1. Freshwater CWT recoveries

2.1.1. Filtering tag code data: ATN vs. ATS

Release strategies for Chinook in the central coast of BC may include releases of fish in their first spring after hatching, or held until late spring or early summer and released as "smolts". The latter strategy is most common with fall or summer Chinook that typically are sub-yearling ocean migrants (ocean-type smolts). However, some Chinook may be held in freshwater for a year after hatching and are referred to as 'yearlings" (stream-type smolts). These juveniles will be much larger than ocean-migrants released in their first spring/summer, and may be used in an attempt to increase the survival of fall or summer Chinook. More typically, this strategy is used for stream-type Chinook salmon. Stream-type Chinook have juveniles that spend one or more years in freshwater before emigrating, and adults return to freshwater for their spawning migration often during the spring and early summer, and spawn in late summer and early fall (Healey 1991). Typically, stream-type Chinook use headwater habitats or systems that have very cool environmental conditions (Riddell 2004).

In 1990 to 1993, an experimental program to produce stream-type smolts was undertaken at Snootli Creek Hatchery. The objective was to determine if smolt-to-adult survival differed between stream-type (hereafter referred to as ATS) and ocean-type (hereafter referred to as ATN) release strategies on Atnarko Chinook. Subsequent CWT recoveries indicated that smolt-to-adult survival of ATS Chinook was approximately double that of ATN fish. This discovery was seen as having tremendous potential. The same number of adults could be produced from fewer broodstock, allowing more returning adults to spawn in the wild, or more adult Chinook could be produced without increasing the number of broodstock taken (DFO 2009). However, this program was cancelled due to funding cuts to the Salmon Enhancement Program and an emphasis on cost-effectiveness. To increase catches while maintaining escapement, Snootli Creek Hatchery proposed to supplement current wild and hatchery production with 400,000 stream-type smolts from the 2007 brood year. The proposal was approved by the PSC Northern Fund. The implementation of these experimental programs is reflected in Table 1, which indicates the numbers of CWT estimated recoveries in all fisheries and in the escapement associated to these endeavours. Given the paucity of CWT recovery data for ATS Chinook, the large amount of data for ATN (Table 2), and the differences in maturation rates (Figure 4) and CWT estimated recoveries across fisheries (particularly Alaska and Central BC Troll fisheries; Figure 5) between ATS and ATN, it was decided to focus the cohort analyses on ATN Chinook in this report and ATS Chinook will be examined when more CWT data are available by the end of the CWT improvement program. In addition to the clear separation of ATN and ATS CWT recoveries, CWT codes from ATN Chinook released in Bella Coola tributaries other than the Atnarko proper were identified and removed from the CWT recoveries in freshwater fisheries and escapement (see Appendix A).

Table 1. Summary of estimated CWT recoveries in fisheries and escapement from ATS (Atnarko Chinook yearling releases) tag codes in examined brood years (1976-2007).

	Brood Year					
Tag Code	1990	1991	1992	1993	2007	Total
020346	184					184
180274					2	2
180325		678				678
180907			213			213
180908			215			215
181238				973		973
Total	184	678	428	973	2	2278

Table 2. Summary of CWT estimated recoveries in fisheries and escapement from ATN (Atnarko Chinook sub-yearling releases) tag codes in examined brood years (1976-2007). There were no releases in 1979, 1980, 2003, and 2004.

	Brood year																												
Tag code	1976	1977	1978	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2005	2006	2007	Total
020246												203																	203
020247												183																	183
020248												186																	186
020249												236																	236
020250												237																	237
020251												221																	221
021428													218																218
021429													336																336
021430													324																324
021521													283																283
021522													205																205
021523													282																282
021732			413																										413
022016	61																												61
022017	12																												12
022018	24																												24
022020		43																											43
022021		17																											17
022022		128																											128
022139					16																								16
022154				240																									240
022155				102																									102
022501					26																								26
022559					20																								20
022739						64																							64
022740						37																							37
022741						49																							49
022755						23																							23
022756						42																							42
023257							150																						150
023258							105																						105
023259							180																						180
023260							78																						78
023641								106																					106
023642								87																					87
023643								87																					87
023644								92																					92
023750								87																					87
023751								81																					81
023752								46																					46
023753								77																					77
024349									49																				49
024350									73																				73
024351									66																				66
024352									103																				103
024353									80																				80
024354									98																				98
024355									45																				45
024356									66																				66
025446										96																			96
025447										100																			100
025448										185																			185
025552										315																			315
025956											263																		263
025957											254																		254
025958											201																		201
025959											181																		181
025960											161																		161
025961											156																		156
180164																												4	4
180166																												16	16
180167																												4	4
180354														1446															1446
180826														771															771
180827														852															852
181222															438														438

Table 2 continued.

	Brood year																												
Tag code	1976	1977	1978	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2005	2006	2007	Total
181223															460														460
181224															325														325
181229																	646												646
181230																	533												533
181236																386													386
181237																415													415
182528																			135										135
182529																			110										110
182530																			139										139
182531																			97										97
182532																			112										112
182533																			196										196
183137																				55									55
183138																				55									55
183139																				48									48
183140																				37									37
183141																				35									35
183142																				32									32
183147																		855											855
183148																		776											776
183801																					256								256
183802																					151								151
183803																					86								86
183804																					196								196
183805																					202								202
183806																					195								195
184354																						240							240
184355																						101							101
184356																						56							56
184357																						57							57
184358																						93							93
184359																						47							47
184649																								288					288
184650																								177					177
184651																								159					159
184652																								318					318
184653																								345					345
184654																								257					257
184819																							218						218
184820																							76						76
184821																							111						111
184822																							59						59
184823																							97						97
184824																							60						60
184935																									323				323
184936																									176				176
184937																									78				78
184938																									95				95
184939																									113				113
184940																									117				117
184947																													82
184948																													51
185304																										376			376
185305																										125			125
185306																										164			164
185425																										123			123
185427																										142			142
185428																										235			235
186205																											136		136
186206																											93		93
186207																											71		71
186208																											33		33
186209																											19		19
186210																											19		19
186362																												36	36
186363																												24	24
Total	97	188	413	342	62	215	513	663	580	696	1216	1266	1648	3069	1223	801	1179	1631	789	262	1086	594	621	1544	902	1165	371	84	23353

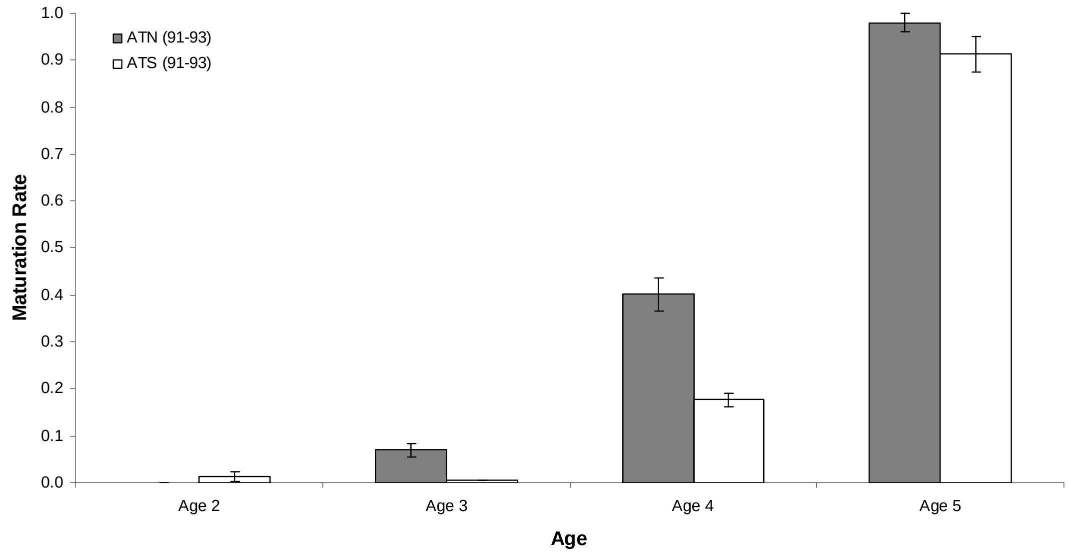


Figure 4. Average maturation rates of Atnarko Chinook sub-yearling release (ATN) and yearling release (ATS) for brood years with available data for ATS (1991-1993). Bars indicate one standard deviation.

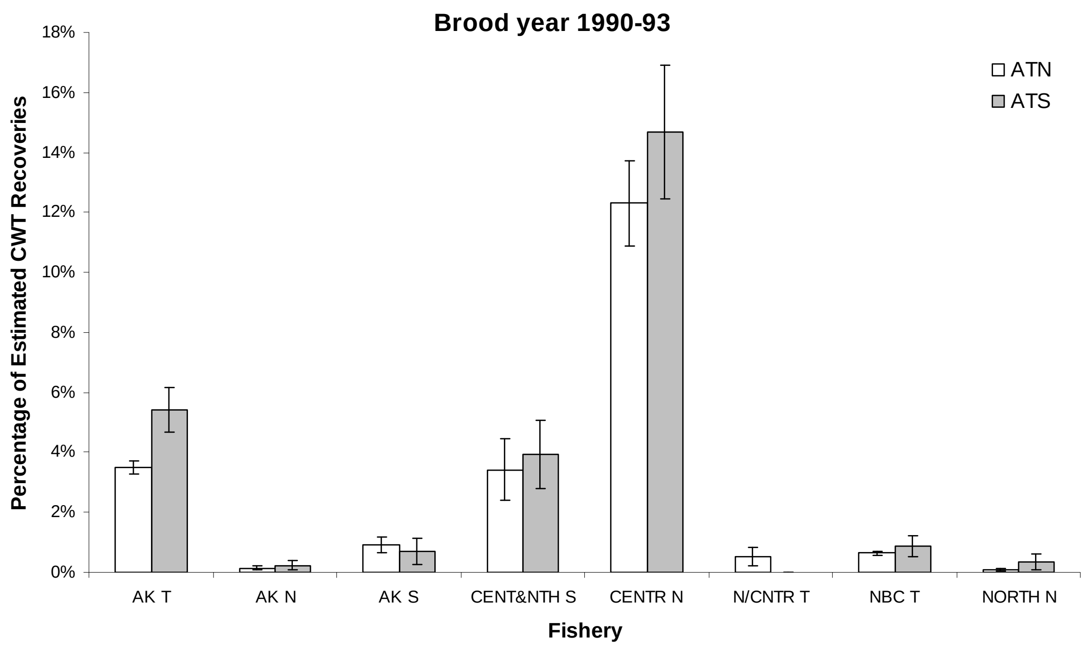


Figure 5. Percentage of estimated CWT recoveries for ATN and ATS by pre-terminal fisheries. Terminal Net, Terminal Sport, and Escapement were accounted for in the percentages. Bars indicate one standard error. Fisheries represented are Alaska Troll, Net and Sport (AK T, AK N, and AK S, respectively), Central and North BC Sport (CENT&NTH S), Central BC Net (CENTR N), Central BC Troll (N/CNTR T), Northern BC Troll (NBC T), and Northern BC Net (NORTH N).

2.1.2. Escapement validation and calibration

Estimates of annual Chinook escapement to the Atnarko River have been produced since 1950 (BCWCS 2007; Appendix B) and terminal run estimates in the Bella Coola River exist since 1980 (Pestal 2004, Riddell 2004; Appendix C). However, uncertainty due to a lack of scrutiny of differences between estimates produced by different methods has limited the reliability of quantitative analyses based on CWT recoveries (Riddell 2004). Mark-recapture experiments before the start of the 5-year CWT Improvement Program (2009 was the first year of this program) have been conducted only sporadically: 1984-1986 (Slaney 1986, Andrew et al. 1988) and 2001-2003 (Sturhahn 2009). Enumeration methods commonly employed for escapement have included carcass surveys, drift net surveys, and adults collected in seine nets to provide broodstock for the Snootli Creek Hatchery, while those employed for fisheries have included commercial catch information collected from aerial gear counts, sales slips, dockside monitoring, observer records from drifts and catches in the Nuxalk FSC fishery, and catch and effort data from the recreational fishery (Pestal 2004). By the beginning of the 1990s, suitability maps combined with expansion factors, fishery officer enumeration areas based on drift counts in high-density river sections, area-under-the-curve estimation (English et al. 1992; Parken et al. 2003), and carcass recoveries (Pitre 1991) constituted common methods to enumerate adult Chinook in the Atnarko. Starting in 1990, escapement estimation has been based on the average of three population estimates produced by different methods (hereafter called 3M Average). These methods generate independent population estimates based on (*i*) CPUE during broodstock collection, (*ii*) carcass counts during deadpitching, and (*iii*) the number of drift-boat surveys.

Atnarko Chinook are easily captured and recovered as this system is not as susceptible to fall flooding as many other coastal Chinook systems (BCWCS 2007). The close proximity of qualified hatchery staff and personnel also reduce the risk inherent with conducting mark-recapture programs on remote systems. Given past mark-recapture and deadpitch programs conducted on the Atnarko there exists a good understanding of effort requirements for sufficient tag application as well as carcass recovery. Past mark-recapture programs have been successful in terms of tagging and recovery rates, thus providing estimates with low coefficients of variation (Appendix D). Escapement estimates derived from mark-recapture studies in 2009 and 2010, as part of the CWT Improvement Program, have also yielded results that meet or exceed the CTC bilateral data standards (i.e., CV < 15%). During the period the 3M Average has been used to generate escapement estimates for Atnarko Chinook (1990-2010), estimates derived from mark-recapture studies have also taken place in 2001, 2002, 2003, 2009 and 2010. Since the consistent compilation of data has enabled the application of the 3M Average (see Appendix E), we used a linear model to predict escapement (E) as function of collected broodstock (B), number of carcasses encountered (C), and the number of drift-boat surveys during carcass counts (D) in a given year (y):

$$E_y = \alpha_1 B_y + \beta_1 C_y + \chi D_y + \varepsilon_1 \quad (1)$$

This model was populated with data from those years with escapement estimates derived from mark-recapture studies (Petersen estimator), and it explained 72% of the variation in escapement estimates with predicted escapement strongly correlated with the Petersen estimates. Other simpler models using only *C* or *B* and *C* as independent variables rendered poorer statistics with $R^2 = 0.61$ for the former and $R^2 = 0.62$ and for the latter. In terms of errors, the *BCD* model exhibited the best fit to the data with a sum of residuals of 7647 versus 8167 and 8979 for the *BC* and *C* models, respectively. Escapement estimates generated by the linear model, the 3M Average, and the Petersen estimator are shown in Figure 6.

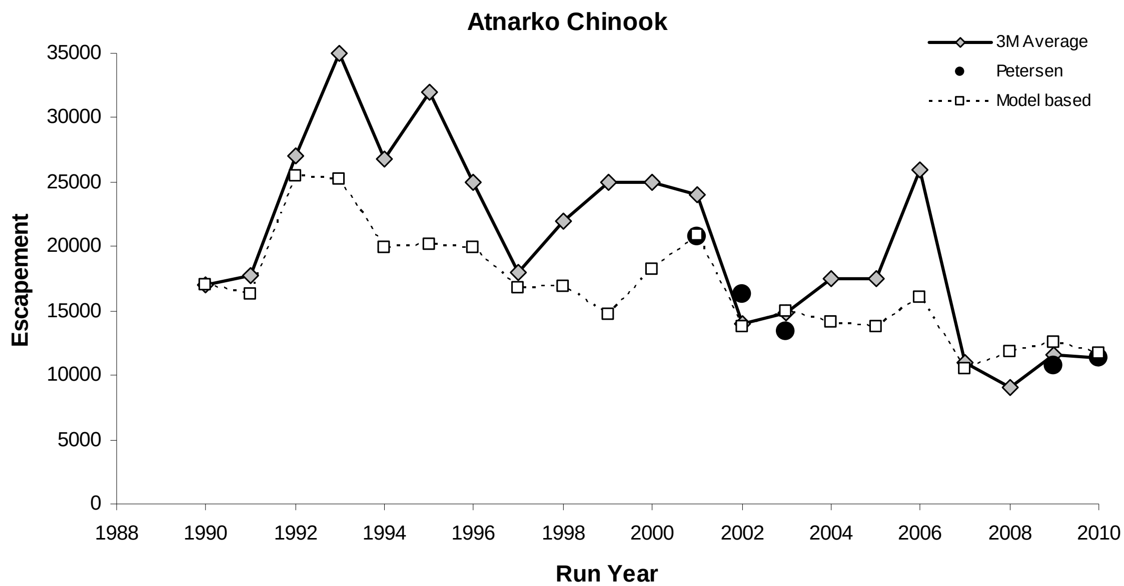


Figure 6. Time series of spawning escapement estimated through the three-method average (3M Average), mark-recapture studies (Petersen estimator), and a predictive linear model. The linear model was based on carcass counts, broodstock collection, and number of drift-boat surveys during deadpitch sampling.

Although we see promise in the linear model to calibrate the time series of escapement, any statistical inference seems currently limited by the small number of data points in the regression (n = 5). In addition, the escapement estimate produced by the 3M Average was similar to the Petersen estimate in all years when mark-recapture studies took place, with the Petersen estimate being on average 97% (SD = 12%) of the estimate produced by the 3M Average and, therefore, indicating no significant differences between estimated values (Wilcoxon matched pair test: z = 0.94; p = 0.35). It was decided: (i) to use a mixed time series with Petersen estimates for years 2001-2003 and 2009-2010 and 3M Average-based escapement estimates for all other years in the time series; and, (ii) to revisit both, the linear model and the 3M Average in 2013, at the end of the CWT Improvement Program, when more years of mark-recapture data are available to further develop and re-evaluate the predictive utility of the linear model.

2.1.3. CWT expansions and sampling fractions

Four CWT recovery strata were included in this analysis: escapement, broodstock, First Nations net fishery (FNFF), and freshwater sport fishery. Estimates of the contribution of hatchery-reared Chinook to the total escapement were calculated by expanding the percentage of CWT's in escapement counts by tag code (Kuhn 1988). Estimating the total number of CWT returns from each CWT code (several CWT codes are generally used in a single brood year), was done as follows.

First, the observed number of CWT recoveries was adjusted to correct for lost pins (tags dissected in the lab but lost before they were read) and no data heads (heads that were lost before they got to the lab):

$$ADJ_{tc,f,y} = OBS_{tc,f,y}\left[1 + \frac{LP}{K} + \frac{ND(K+LP)}{K(K+LP+NP)}\right] \qquad (2)$$

where $ADJ_{tc,f,y}$ is the adjusted number of observed CWT fish for a particular tag code (*tc*), fishery (or escapement; *f*), and recovery year (*y*), $OBS_{tc,f,y}$ is the observed number of CWT fish, *K* is the sum of all successfully decoded tags for all tag codes recovered in a particular stratum, *LP* is the number of lost pin recoveries, *ND* is the number of no data recoveries, *NP* is the number of no pin recoveries. This adjusted number of CWT recoveries was then used to estimate the total number of CWT returns for each tag code in the escapement:

$$EST_{tc,y} = \frac{ADJ_{tc,f,y}\ E_y}{N_y} \qquad (3)$$

where $EST_{tc,y}$ is the estimated number of CWT recoveries for a single tag code, N_y is the number of fish examined (carcasses recovered in this case), and E_y is the escapement estimate for year *y*. Note that the sum of $EST_{tc,y}$ values for all tag codes represents the number of hatchery-marked fish in the spawning escapement in year *y*. Since 100% of the fish in the broodstock are accounted for, $EST_{tc,y}$ was identical to $ADJ_{tc,f,y}$ (i.e., expansion factors are not needed) in this recovery stratum.

The hatchery contribution to escapement or broodstock was calculated by expanding the estimated number of CWT fish of each tag code group in proportion to the percentage of juvenile fish having a CWT at time of release:

$$EHC_{tc,y} = \frac{EST_{tc,y}(RM_{tc} + RUM_{tc})}{RM_{tc}} \qquad (4)$$

where $EHC_{tc,y}$ is the estimated hatchery contribution, RM_{tc} is the number of Chinook released with CWTs for each tag code group, and RUM_{tc} is the number of Chinook released without CWTs for each tag code group. These estimates of hatchery contribution by tag code were then summed across all tag codes to the entire escapement (or broodstock) in a given recovery year to determine the proportion of hatchery fish.

The ratio between the total number of estimated tags in the escapement ($EST_{tag,y} = \Sigma EST_{tc,y}$) and fishery-specific harvest rate was used to compute the total number of estimated tags in the two freshwater fisheries ($X_{tag,f,y}$), Bella Coola First Nations net (FNFF) and Bella Coola-Atnarko sport, following equation 5:

$$X_{tag,f,y} = \left[\frac{EST_{tag,y}}{\dfrac{E_y}{C_{f,y}Z_{f,y} + E_y}} \right] \text{x} \left[\frac{C_{f,y}Z_{f,y}}{C_{f,y}Z_{f,y} + E_y} \right] \qquad (5)$$

where $C_{f,y}$ is the landed catch in fishery f, $Z_{f,y}$ is a correction factor that in this case represents the proportion of Atnarko Chinook in fishery f. The inclusion of $Z_{f,y}$ is necessary since the assumption that all Chinook captured in the Bella Coola system are Atnarko fish is not always true. The correction factor was computed as a ratio of the mark rates in the catch and escapement at 100% sampling:

$$Z_{f,y} = \frac{\dfrac{ADJ_{tag,f,y}}{C_{f,y}}}{\dfrac{EST_{tag,y}}{E_y}} \qquad (6)$$

where $ADJ_{tag,f,y}$ is the sum of $ADJ_{tc,f,y}$ for all tag codes recovered in year y. The term $Z_{f,y}$ was assumed to be 1.00 in the sport fishery since its mark rates are unknown, thus assuming that 100% of caught fish were Atnarko Chinook. This assumption seems valid since only two recoveries of non-Atnarko Chinook occurred from 1990 to 2010. The non-Atnarko recoveries were released in one of the Bella Coola tributaries, Salloomt River, and they were tag codes 180837 (brood year 1991) and 184548 (brood year 1999).

Finally, the sampling fraction ($SF_{f,y}$) was computed as the ratio of the total number of observed tags in fishery f ($ADJ_{tag,f,y}$) and the corresponding estimated tags ($X_{tag,f,y}$), and the number of estimated CWT recoveries by tag code in the fishery ($EST_{tc,f,y}$) was computed as:

$$EST_{tc,f,y} = \frac{ADJ_{tc,f,y}}{SF_{f,y}} \qquad (7)$$

2.1.4. Terminal Central Net

The examination of CWT recoveries in the commercial net fishery in the Bella Coola (hereafter referred to as Terminal Central Net) showed that in spite of counting with catch records from 1980 to 2010, no CWT recoveries were recorded from 2003 to 2008 due to lack of CWT sampling, sampling occurred in 2009, and poor sampling took place in 2010 (there were three recoveries). Thus, CWT pseudo-recoveries were generated for years 2003-2008 and 2010 using linear models projecting estimated ATN CWT recoveries by age a in recovery year y ($R_{a,y}$) as function of the number of CWTed Chinook salmon released in brood year $by = y\text{-}a$ ($REL_{by=y-a}$) and the Terminal Central Net Catch in recovery year $y = by{+}a$ ($C_{y=by+a}$):

$$R_{a,y} = \alpha_2 REL_{by=y-a} + \beta_2 C_{y=by+a} + \varepsilon_2 \tag{8}$$

where $\boldsymbol{\alpha}_2$ and $\boldsymbol{\beta}_2$ are model parameters and $\boldsymbol{\varepsilon}_2$ is the associated error. It was necessary to develop a single model for each age (Table 3) because the lack of releases in years 2003 and 2004 prevented the use of an alternative, simpler approach using a single model for the most representative age and the average age contributions to extrapolate recoveries to other recovered age-class recoveries (see Section 2.2.2). The models were populated with released data covering the period 1976-2000 and catch data covering the period 1977-2002.

Table 3. ANOVA results of age-specific models for estimated CWT Atnarko Summer (ATN) recoveries in Terminal Central Net with number of CWTd fish released in brood year *by* = *y*-*a* and catch in recovery year *y* = *by*+*a* as independent variables.

Model	Source	DF	SS	MS	F Ratio	Prob > F
Age-2 recoveries	Model	2	75.00307	37.5015	8.9432	0.0017
	Residuals	20	83.86649	4.1933		
Age-3 recoveries	Model	2	5391.387	2695.69	4.08	0.0327
	Residuals	20	13214.09	660.7		
Age-4 recoveries	Model	2	9910.701	4955.35	3.1787	0.0633
	Residuals	20	31178.6	1558.93		
Age-5 recoveries	Model	2	15187.64	7593.82	7.3271	0.0044
	Residuals	19	19691.68	1036.4		
Age-6 recoveries	Model	2	36.68823	18.3441	3.4199	0.0551
	Residuals	18	96.54986	5.3639		

CWT estimated recoveries from an individual tag code are summarized into an input file for the program used to run cohort analyses (COHSHK11; see next section). These tag code-specific files are called C-files. Since COHSHK11 combines the recoveries from all tag codes in a given brood year, specific tag code C-files were modified to incorporate the model-based estimated CWTs by age recovered in Terminal Central Net (Table 4). Each of the modified C-files carried the pseudo-recoveries by age generated by individual models (Table 5).

Table 4. Model-based estimated CWTs by age recovered in Terminal Central Net for years 2003-10. The number of estimated recoveries derived from observed data (154) was used for year 2009. Colors correspond to those in Table 5.

	Models					
Recovery Year	Age 2	Age 3	Age 4	Age 5	Age 6	All ages
2003	0	19.76158	60.3974	64.52535	1.916075	147
2004	0	20.62044	59.18318	60.32047	1.789788	142
2005	0	24.67293	58.16982	60.70905	1.645573	145
2006	0	0	61.69007	60.81014	1.656719	124
2007	0	0	0	65.02851	1.641172	67
2008	0	12.32611	0	0	1.707394	14
2009	0	3.229336	54.6707	0	0	**154**
2010	0	0	48.20086	54.97261	0	103

Table 5. Tag code C-files modified with CWT pseudo-recoveries in Terminal Central Net. Colors correspond to those in Table 4.

Modified codes	Brood year	Estimated number	Age
183137	1997	2	6
183801	1998	65	5
183801	1998	2	6
184354	1999	60	4
184354	1999	60	5
184354	1999	2	6
184819	2000	20	3
184819	2000	59	4
184819	2000	61	5
184819	2000	2	6
184649	2001	21	3
184649	2001	58	4
184649	2001	61	5
184649	2001	2	6
184935	2002	25	3
184935	2002	62	4
184935	2002	65	5
184935	2002	2	6
185304	2005	12	3
185304	2005	151	4
185304	2005	55	5
186205	2006	3	3
186205	2006	48	4

2.2. Cohort analysis

2.2.1 Annual exploitation rate analysis

For additional analytical detail on cohort analysis of PST Chinook salmon see PSC (1988). Briefly (see Table 6 for a description of notation), the exploitation rate on an indicator stock may differ from the exploitation rate on the wild stock it represents when there are terminal fisheries directed at harvesting surplus hatchery production. In the case of the brood year exploitation rate, this difference was addressed by computing a rate for ocean fisheries and a total for all fisheries. Ocean fisheries were defined to include marine sport and troll fisheries and CWT recoveries of ocean age-2 and age-3 fish in all non-terminal net fisheries outside of PFMA 8. By partitioning the fisheries in this way, the most appropriate measure of brood year exploitation rate on wild stocks could be selected. If broods are incomplete, but have data through age 4 (age 5 for stream-type stocks), then average maturation rates are applied to predict the completed brood value.

The brood year exploitation rate (*BYEXP*) is calculated as:

$$BYEXP_{BY,F} = \frac{\sum_{a=Minage}^{Maxage}\left(\sum_{f\in\{F\}} TotMorts_{BY,a,f} * AEQ_{BY,a,f}\right)}{\sum_{a=Minage}^{Maxage}\left(\sum_{f=1}^{Numfisheries} TotMorts_{BY,a,f} * AEQ_{BY,a,f} + Esc_{BY,a}\right)} \tag{9}$$

The adult equivalent (AEQ[3]) rate is calculated as:

$$\begin{aligned} AEQ_{BY,a-1,f} &= MatRte_{a-1,BY} + (1 - MatRte_{a-1,BY}) * Surv_a * AEQ_{BY,a,f} \\ AEQ_{BY,Maxage,f} &\equiv 1.0 \end{aligned} \tag{10}$$

The survival rate for a stock and brood year is the estimated age-2 cohort (from the cohort analysis of CWT data) divided by the number of CWT fish released.

$$Age2CohSurv_{BY} = \frac{Cohort_{BY,2}}{TotCWTRelease_{BY}} \tag{11}$$

where $Cohort_{BY,2}$ is calculated recursively from the oldest age down to age-2 using:

$$Cohort_{BY,a} = \frac{\sum_{f=1}^{Numfisheries} TotMorts_{BY,a,f} + Esc_{BY,a} + Cohort_{BY,a+1}}{1 - NM_a} \tag{12}$$

[3] The Chinook Technical Committee (CTC) has defined an AEQ as the probability a fish of a given age would survive to reach its stock's terminal area in the absence of fishing, thus taking into account the age and stock-specific maturation schedule.

If ocean age-5 tags are absent, the age-4 cohort size is estimated using the following formula:

$$Cohort_{BY,4} = \frac{\sum_{f \in Preterminal} TotMorts_{BY,4,f} + \dfrac{Esc_{BY,4} + \sum_{f \in Terminal} TotMorts_{BY,4,f}}{AvgMatRte_4}}{1 - NM_4} \quad (13)$$

Brood year exploitation rates can indicate the fisheries that exploit a stock and the rates that occur on a specific brood, but do not indicate the exploitation pattern on a stock during one calendar year (across broods). Stock mortality distributions (reported catch or total) in a calendar year are calculated over all ages in the fisheries (if at least three brood years contribute to recoveries) as follows:

$$CYDist_{CY,F} = \frac{\sum_{a=Minage}^{Maxage} \sum_{f \in \{F\}} Morts_{CY,a,f} * AEQ_{BY=CY-a,a,f}}{\sum_{a=Minage}^{Maxage} \left(\sum_{f=1}^{Numfisheries} Morts_{CY,a,f} * AEQ_{BY=CY-a,a,f} + Esc_{CY,a} \right)} \quad (14)$$

Fishery indices can be then computed in AEQs for both reported catch and total mortality (reported catch plus estimated incidental mortality). The total mortality index provides a consistent means of representing changes in reported catch and incidental mortality, including those associated with regulatory measures such as minimum size limits and non-retention periods. The AEQ exploitation rate (ER) is estimated by;

$$ER_{s,a,f,CY} = \frac{TotMorts_{s,a,f,CY} * AEQ_{s,BY=CY-a,a,f}}{Cohort_{s,BY=CY-a,a} * (1 - NM_a)} \quad (15)$$

and a ratio of means estimator is used to calculate a fishery index (FI) that measures changes in harvest rates relative to the base period (1979-1982) specified in the Pacific Salmon Treaty,

$$FI_{f,CY} = \frac{\sum_{s \in \{S\}} \sum_{a \in \{A\}} ER_{s,a,f,CY}}{\left(\dfrac{\sum_{BPER=79}^{82} \sum_{s \in \{S\}} \sum_{a \in \{A\}} ER_{s,a,f,BPER}}{4} \right)} \quad (16)$$

Table 6. Parameter definitions for all equations related to cohort analysis.

Parameter	Description
a =	age class
A=	set of all ages that meet selection criteria
$AEQ_{BY,a,f}$ =	adult equivalent factor in brood year *BY*, age *a*, and fishery *f* (for terminal fisheries, AEQ = 1.0 for all ages)
$Age2CohSurv_{BY}$ =	cohort survival of CWT fish to age 2 (pre-fishery) for brood year *BY*
$AvgMatRte_a$=	average maturation rate for age *a*
$BYEXP_{BY,F}$ =	brood year exploitation rate in adult equivalent for brood year *BY* and fishery *F*
BPER=	base period years (1979 through 1982)
BY =	brood year
$Cohort_{BY,a}$=	cohort by brood year *BY* and age *a (where stock is implied from context)*
CY =	calendar year
$CYDist_{\mathrm{CY,F}}$ =	proportion of total stock mortality (or escapement) in a calendar year *CY* attributable to a fishery or a set of fisheries *F*
$Esc_{\mathrm{Y,a}}$ =	escapement past all fisheries for either brood year *BY* or calendar year *CY* and age *a*
$ER_{s,a,f,CY}$ =	exploitation rate (based on total mortality) at age *a* divided by cohort size at age *a* for stock s in fishery *f* in year *CY*
f =	a single fishery
$f \in \{F\}$ =	a fishery *f* within the set of fisheries of interest
F =	ocean, terminal or other sets of fisheries or spawning escapements
$FI_{f,CY}$ =	fishery exploitation rate index for fishery *f* in year *CY*
$MatRte_{a\text{-}1,BY}$ =	maturity rate at next younger age by brood year
Maxage =	maximum age of stock (generally age 6 for stream type stocks, age 5 for ocean type stocks)
Minage =	minimum age of stock (generally age 3 for stream type stocks, age 2 for ocean type stocks)
$Morts_{CY,a,f}$ =	landed or total fishing mortality in year *CY* and age *a* in fishery *f*
NM_a =	annual natural mortality prior to fishing on age *a* cohort
s =	a particular stock
S =	set of all stocks that meet selection criteria
SC_{BY} =	ratio of the estimated and model predicted terminal run for brood year *BY*
$Surv_a$ =	survival rate ($1\text{-}NM_a$) by age
$TotMorts_{BY,a,f}$ =	total fishing related mortality for brood year *BY* or calendar year *CY* or during the base period *BPER* and age *a* in fishery *f*
$TotCWTRelease_{BY}$ =	number of CWT fish released in the indicator group in brood year *BY*

Two computer programs developed by the CTC were used to run the cohort analyses for Atnarko Chinook, COSHAK4.VB08_V1.2.5 (hereafter COSHAK4) and COHSHK11e (see Appendix F). The primary purpose of both programs is to summarize CWT recoveries from several tag codes. Estimated CWT recoveries of an individual tag code are combined in a C-file. C-files from selected tag codes are used as input files for these two programs. The summarization may aggregate several tag codes and/or fisheries. COSHAK4 was used to estimate the CWT recoveries in the base period 1979-1982 given escapement pseudo-recoveries or CWT recoveries during a different set of recovery years (see Appendix G). The latter is called the out-of-base (OOB) procedure and uses a file (WG4) that contains the harvest rate scalars that are used to adjust the CWT recoveries. The file includes the first and last year in the analysis, and harvest rate indices for landed catch during the time period for all fisheries for which the data are available. COHSHK11e was used to generate parameters associated to the annual exploitation rate analysis such as annual distribution of catch and total fishing mortalities, exploitation rates, maturation rates, and age-2 cohort survival.

2.2.2. Base-period data and analyses

COSHAK4 was used to run cohort analyses of Atnarko Chinook using two different procedures to generate escapement estimated recoveries. First, we used a combination of the escapement and maturation rate options in COSHAK4 (Appendix G), with escapement pseudo-recoveries used to run the program with the escapement option and then using the maturation rates produced by this run to execute the program again using the maturation rate option. As a second approach, we used CWT recoveries from brood years 1987-1990 to run the OOB procedure.

Using the escapement option in COSHAK4

Escapement pseudo-recoveries by age for brood years 1976-1978 contributing to base period (1979-1982) escapement recoveries were generated with a linear model (equation 17). Two age-specific models were explored (Table 7), one for projections of age-4 escapement recoveries and one for age-5 recoveries, where estimated ATN CWT recoveries in recovery year y ($R_{a,y}$) were estimated as function of CWT releases in brood year $by = y\text{-}a$ ($REL_{by=y-a}$) and escapement in recovery year $y = by+a$ ($E_{y=by+a}$)

$$R_{a,y} = \alpha_3 REL_{by=y-a} + \beta_3 E_{y=by+a} + \varepsilon_3 \qquad (17)$$

The models were populated with released data covering the period 1986-2006 and escapement data covering the period 1990-2010. The linear model for age-4 recoveries was preferred since the sum of residuals was about half (RMSE = 153) of that from the alternative model (RMSE = 295). Estimated CWT recoveries for ages 2, 3, 5, and 6 were then generated by combining the model-based age-4 recoveries and the average percent age contributions (age-2: 0.31%; age-3: 8.13%; age-4: 33.66%; age-5: 55.06%; age-6: 2.84%) of estimated CWT recoveries in 1990-2010. Model-based estimated CWT recoveries by age for brood years 1976-1978 (Table 8) were then entered manually to run COSHAK4 (hereafter called escapement procedure).

Table 7. ANOVA results of two models for age-specific CWT Atnarko Summer (ATN) escapement recoveries with number of CWTd fish released in brood year *by* = *y*-*a* and escapement in recovery year *y* = *by*+*a* as independent variables.

Model	Source	DF	SS	MS	F Ratio	Prob > F
Age-4 escapement recoveries	Model	2	1444049.2	722025	30.679	< 0.001
	Residuals	19	447162	23535		
Age-5 escapement recoveries	Model	2	3888323.8	1944162	22.3193	< 0.001
	Residuals	19	1655029.6	87107		

Table 8. Model-based estimated CWT recoveries by age for brood years contributing to base period (1979-1982) escapement recoveries. Recoveries were generated with the model for age-4 escapement recoveries and the percent age contributions (age-2: 0.31%; age-3: 8.13%; age-4: 33.66%; age-5: 55.06%; age-6: 2.84%) of estimated CWT recoveries in the escapement for examined years (1990-2010).

	AGE					
Brood Year	2	3	4	5	6	Total
1976	0.8	22.0	91.0	148.8	7.7	270.3
1977	0.6	16.0	66.4	108.6	5.6	197.2
1978	1.0	25.3	104.8	171.4	8.8	311.3

Using the out-of-base procedure in COSHAK4

The OOB procedure in COSHAK4 was used as an alternative approach to generate CWT base period data. Various trials of this procedure were ran with the goal of identifying an appropriate set of brood years under three main criteria: proximity to the base period (1979-1982), adequate CWT recoveries from those brood years, and the generation of output files with no apparent anomalies in the structure of cohort size by age, maturation rates, and exploitation rates. Based on these criteria, CWT recoveries from tag codes representing brood years 1987-1990 were used to run the OOB procedure. In addition, this procedure requires scaling fishery levels during the selected period (1987-1990) to represent fishing levels in the base period. The WG4 file serves this function; it contains the harvest rate indices by fishery (i.e., fishery indices) used to adjust the CWT recoveries using the OOB procedure in COSHAK4. The fishery indices in the WG4 represent the ratio the harvest rate in a particular year and the average during the base period (1979-82).

There is a generic WG4 used for the implementation of OOB procedures in cohort analyses of PSC CWT stocks. This file can be customized to represent more closely changes in fishing levels between time periods. In order to modify the WG4 file, data from CTC fishery policy scalars for Central Net, summarized in what is called the CENTRL N.FPA file, were compared to a time series of fishery indices generated as the ratio of the harvest rate in commercial net in the Bella Coola in a given year and the average harvest rate observed for the same fishery in the base period. Fishery index values in this new time series were generally greater than values in the generic WG4 and lower than those in the FPA file (Figure 7). Since this new time series of fishery indices (ATN TCENTRL N) represents exactly changes in fishing levels in Chinook Terminal Central Net, we used it to modify the generic WG4 and run the OOB procedure.

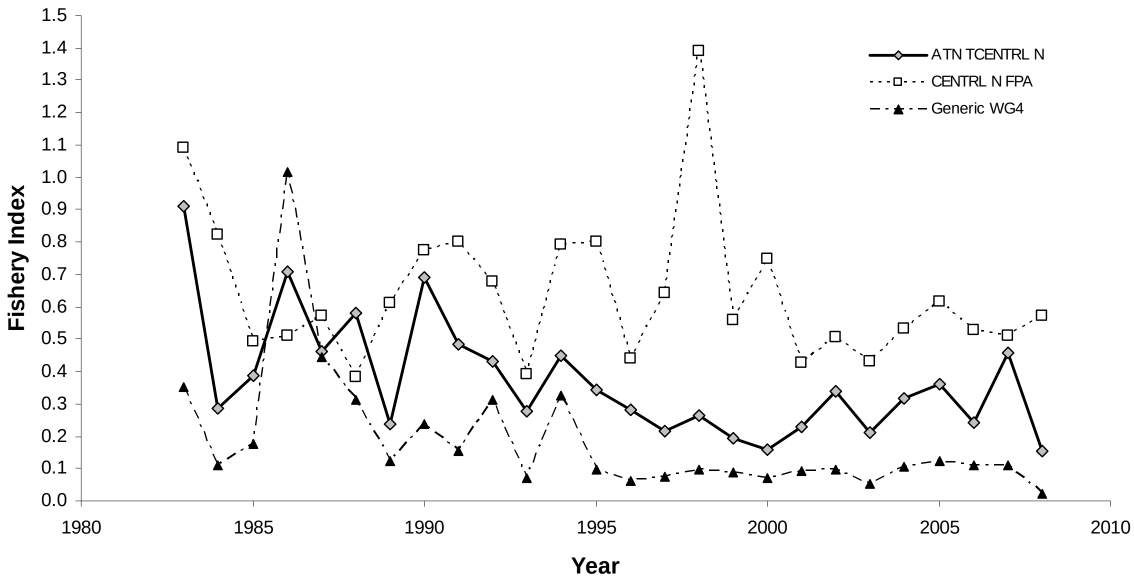


Figure 7. Time series of fishery indices available for the implementation of the out-of-base cohort analysis procedure: (1) ATN TCENTRL N represents commercial seine and gillnet in the Bella Coola; (2) CENTRL N FPA includes tidal and non-tidal First Nations catch and Bella Coola commercial gillnet; and (3) Generic WG4 represents the fishery index currently used in the generic file used by COSHAK4.

3. RESULTS

3.1. Freshwater estimated CWT recoveries

Hatchery contributions for the examined period (1990-2010) averaged 34% (range: 13% - 67%) in the escapement and 52% (range: 12% - 96%) in the broodstock with the percentage of hatchery fish consistently higher in the broodstock than in the escapement (excepting 2008). This consistency indicates a positive selectivity of marked fish for hatchery purposes. The sharp decrease observed between 2006 and 2008 is associated to the absence of CWT releases for brood years 2003 and 2004 (Figure 8).

Mark rates averaged 3.03% (range: 1.16% - 7.45%) in the escapement and 2.15% (range: 1.00% - 4.71%) in the FNFF, producing correction factors that indicated an average 73.14% (range: 47.14% - 100.00%) of Atnarko Chinook (ATN) in the FNFF. Corresponding sampling fractions averaged 86% (range: 79% - 100%) in the FNFF and 23% (range: 6% - 40%) in the sport fishery (Figure 9).

The time series of estimated CWT recoveries for Terminal Central Net (Figure 10) shows a sharp decline in recoveries from 2006 to 2008, which is influenced strongly by the lack of CWT releases for brood years 2003 and 2004. The largest number of estimated recoveries (346) occurred in 1995.

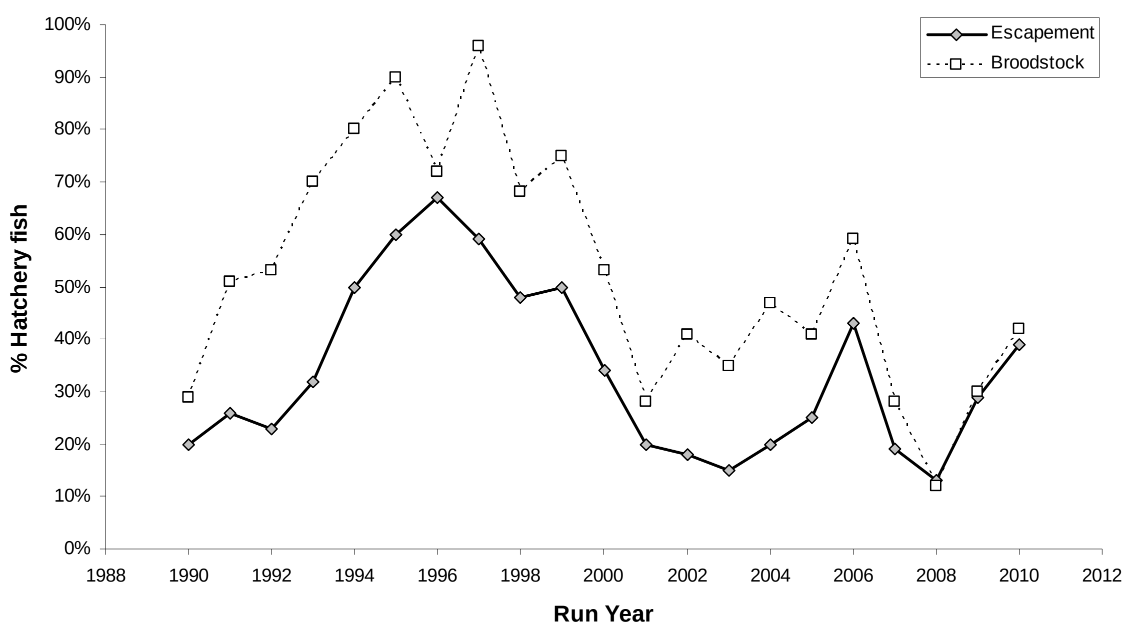


Figure 8. Hatchery contributions to Atnarko Chinook escapement and broodstock (1990-2010).

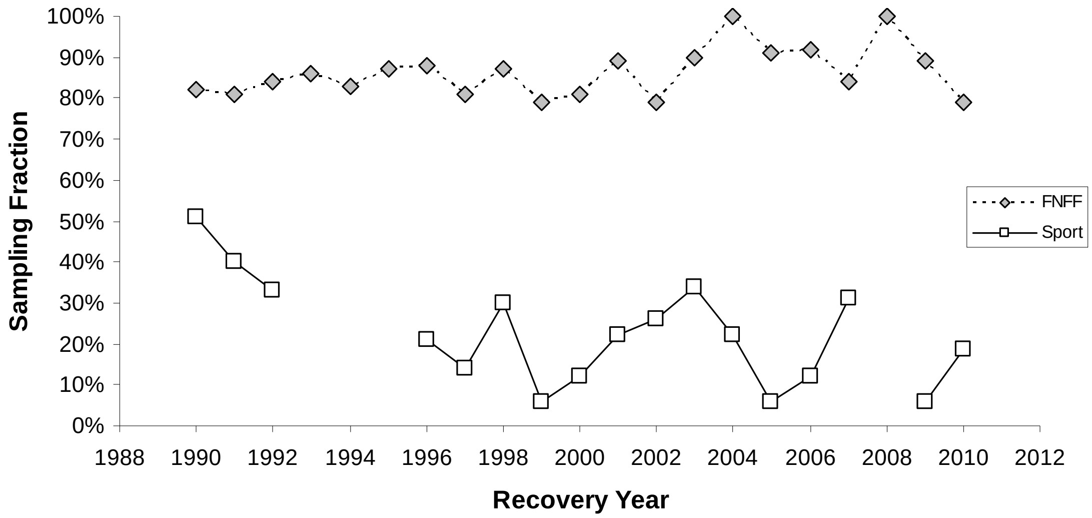


Figure 9. Sampling rates for First Nations net (FNFF) and sport fisheries from 1990 to 2010.

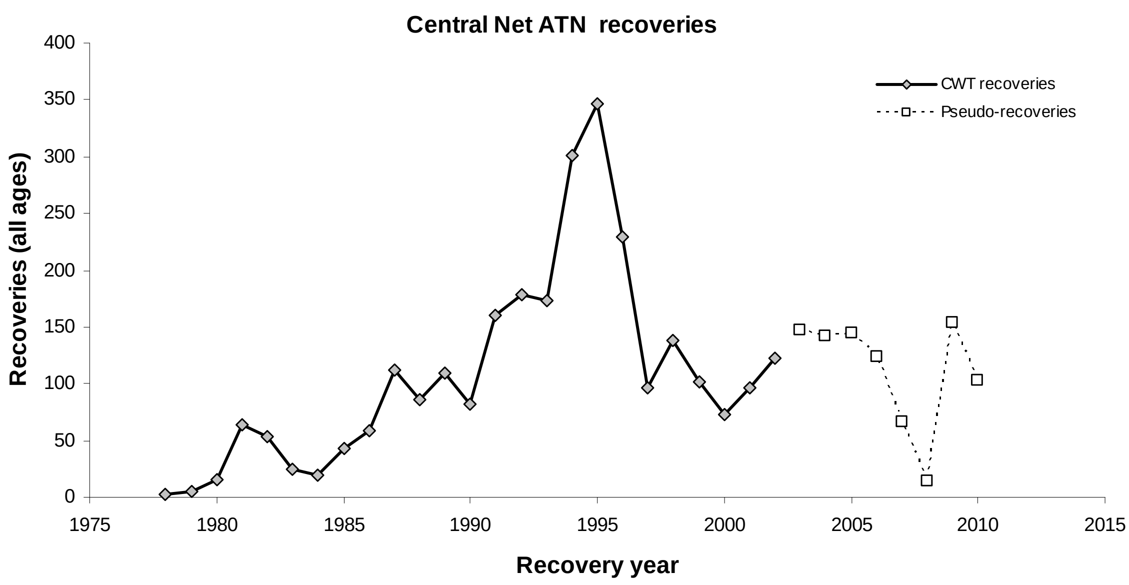


Figure 10. Time series of estimated CWT Atnarko (ATN) recoveries in Terminal Central Net (all ages pooled). The time series shows years with true recoveries and model-based pseudo-recoveries.

The vast majority of estimated freshwater CWT recoveries occurred in the escapement, with FNFF and sport fisheries showing relatively small contributions across brood years and recovery years. Estimated CWT recoveries by brood year increased from 1984 to 1991 when a maximum number of recoveries occurred, and then declined to lower levels (Figure 11). No CWT releases occurred in brood years 2003 and 2004, which contributed to the low recoveries in catch years 2006 and 2007.

In terms of recovery years (i.e., catch years), the change in recoveries between consecutive years is smoother than in the brood year time series, with a steady increase in estimated CWT recoveries from 1990 to 1996, when a maximum number of recoveries occurred, and a decline afterwards up to 2004. Year 2006 shows the largest number of CWT recoveries in the last decade. The effect of lack of releases in 2003 and 2004 seems to have had larger consequences for recoveries in 2008 when the smallest number of recoveries occurred and when CWTed Chinook were only recovered in the escapement (Figure 12).

Most of the ATN estimated CWT recoveries in both, escapement and broodstock were represented by age-4 and age-5 fish, with low recoveries of age-3 fish and even lower recoveries of age-2 or age-7 fish (Figure 13). Noticeable age-2 recoveries took place only on recovery years 1994 and 1995 in the escapement and 1990 in the broodstock, while age-7 recoveries happened only in 1995 in the escapement and did not occur in the broodstock. Anomalies in CWT estimated recoveries in escapement and broodstock occurred as a result of the lack of CWTed Chinook releases in 2003 and 2004, with 2008 exhibiting only age-3 recoveries in both recovery strata. The reading of scales (Aging Laboratory, DFO Pacific Biological Station, Nanaimo BC) revealed average age percent contributions of ocean-type Atnarko Chinook in the escapement similar to those estimated from CWT data (Table 9), with a Wilcoxon Matched Pair Test indicating non-significant differences between the two samples ($Z = 0.105$; $p = 0.92$)

A dominance of age-4 and age-5 CWT estimated recoveries also occurred in the FNFF and in the sport fishery, with recovery peaks occurring in 1995-1998 for the former and 1996 the latter. Interestingly, only age-3 CWTed fish were recovered in 2005. The influence of the lack of releases in 2003-2004 was also apparent in the last years of the time series, which were characterized by low recoveries and anomalous age composition (Figure 14). In addition, no CWTs were recovered from the sport fishery in 1992-1994 and 2008.

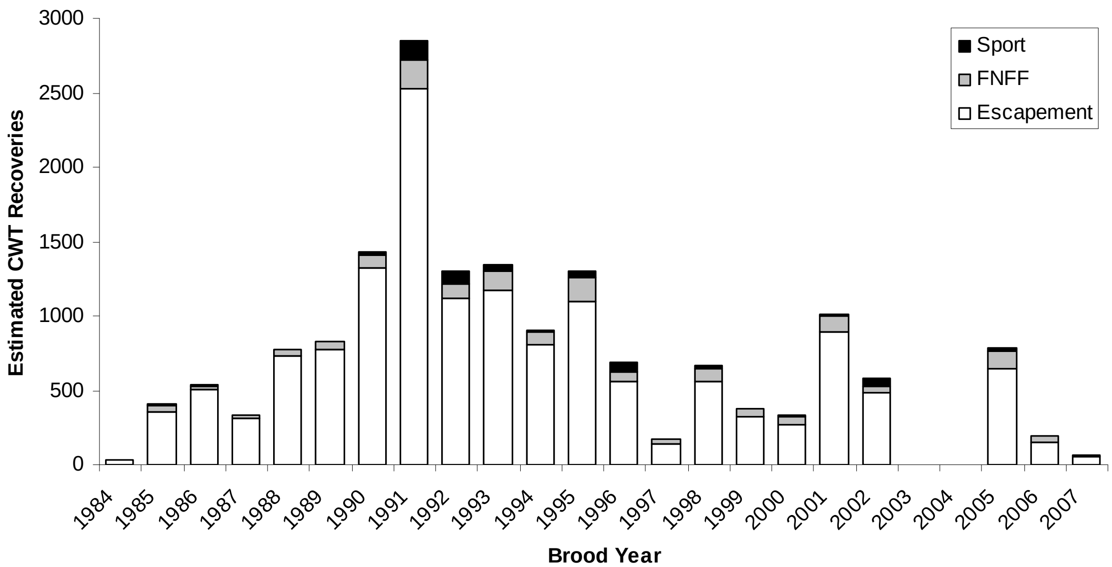


Figure 11. Estimated CWT terminal recoveries by brood year in sport and First Nations Food Fishery (FNFF) fisheries and escapement (includes broodstock) of Atnarko Chinook (ATN).

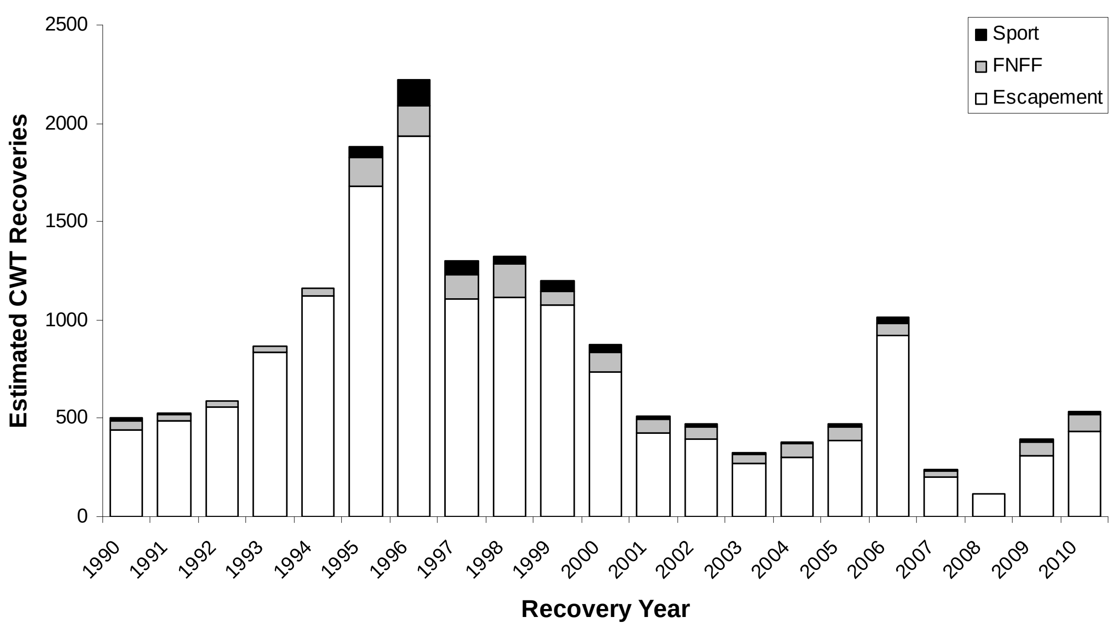


Figure 12. Estimated CWT terminal recoveries by recovery year in sport and First Nations Food Fishery (FNFF) fisheries and escapement (includes broodstock) of Atnarko Chinook (ATN).

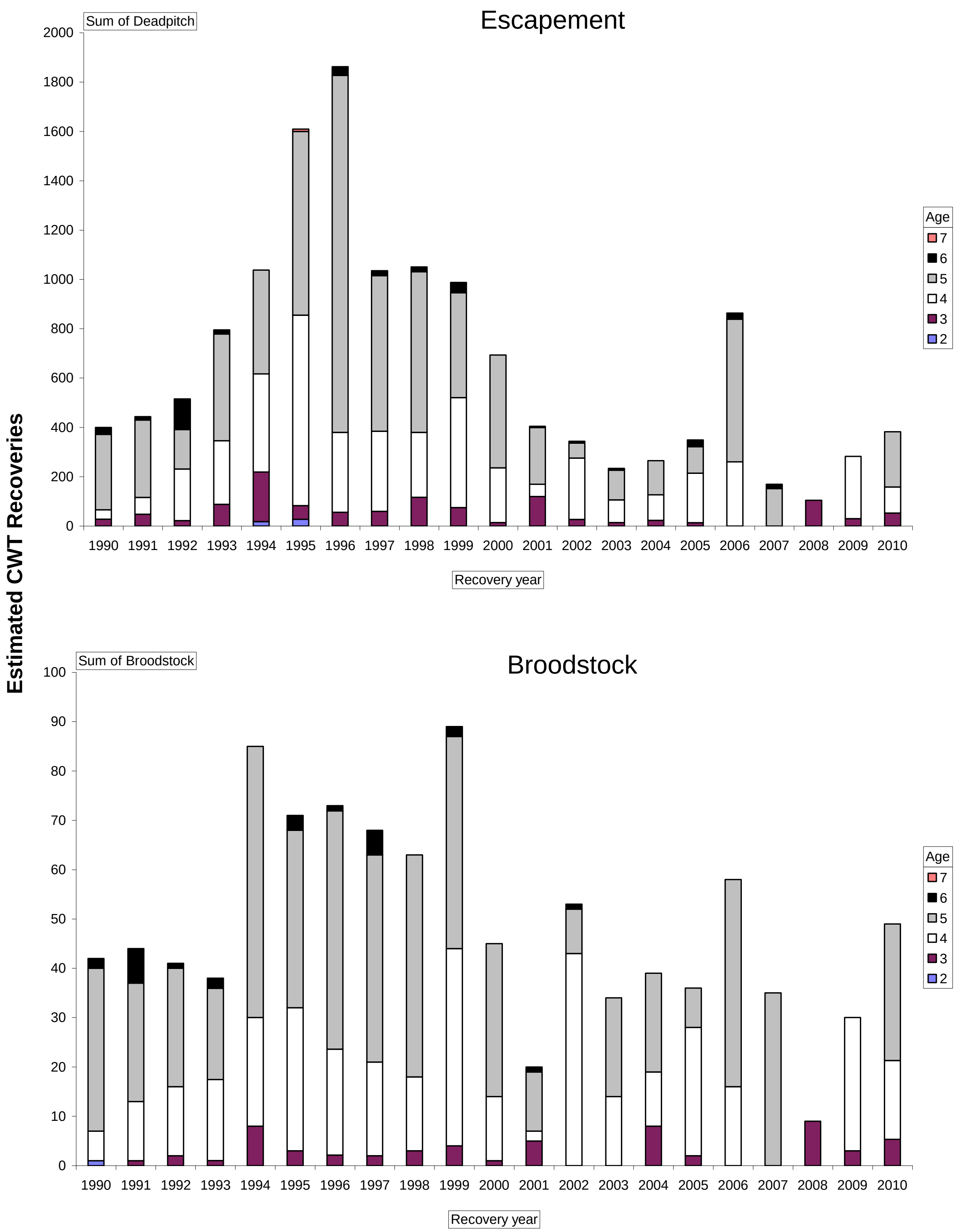


Figure 13. Estimated CWT terminal recoveries by age and recovery year in escapement and broodstock of Atnarko Chinook (ATN).

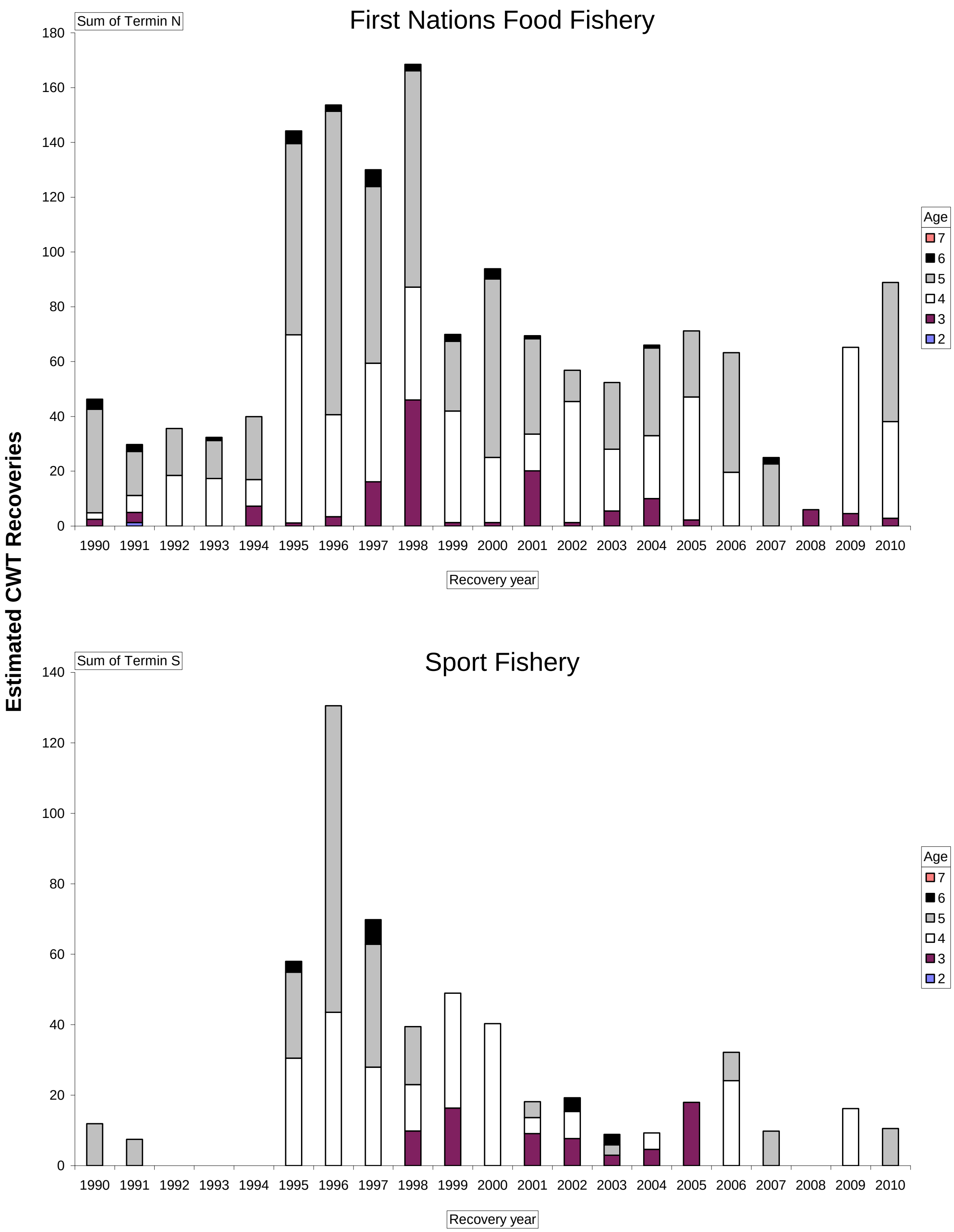


Figure 14. Estimated CWT terminal recoveries by age and recovery year in First Nations and sport fisheries of Atnarko Chinook (ATN).

Table 9. Age percent contributions of ocean-type Atnarko Chinook in the escapement as determined from scales. Percent contributions determined from observed and estimated CWT escapement recoveries are shown in the last two rows for comparison.

Year	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7
1989	0.00%	1.72%	21.55%	75.86%	0.86%	0.00%
1990	0.00%	6.90%	29.31%	63.79%	0.00%	0.00%
1991	0.00%	6.17%	25.93%	66.67%	1.23%	0.00%
1992	0.00%	6.74%	44.94%	48.31%	0.00%	0.00%
2001	0.00%	23.58%	18.78%	56.33%	1.31%	0.00%
2002	0.43%	9.13%	61.30%	28.26%	0.87%	0.00%
2003	1.89%	10.38%	45.28%	42.45%	0.00%	0.00%
2004	0.00%	4.17%	41.67%	50.00%	4.17%	0.00%
2005	0.00%	1.92%	50.00%	44.23%	3.85%	0.00%
2006	0.00%	3.18%	31.85%	63.69%	1.27%	0.00%
2007	0.00%	0.00%	20.00%	76.00%	4.00%	0.00%
2008	0.00%	31.34%	32.84%	32.84%	2.99%	0.00%
2009	0.20%	17.31%	62.73%	19.35%	0.41%	0.00%
2010	0.00%	12.45%	35.02%	52.14%	0.39%	0.00%
Average (1989-2010)	0.18%	9.64%	37.23%	51.42%	1.52%	0.00%
Average (1990-2010) Observed CWT	0.04%	8.24%	34.01%	55.92%	1.76%	0.04%
					* Age 6+	
Average (1990-2010) Estimated CWT	0.31%	8.13%	33.66%	55.06%	2.84%	

* Age classes 6 and 7 were pooled in the case of estimated CWT recoveries

3.2. Cohort analyses

After filling data gaps in freshwater CWT recoveries and generating sampling fractions for expansions of observed CWT into estimated CWT recoveries, C-files were created for individual tag codes (Appendix H) contributing to recovery years 1990-2010, and cohort analyses of Atnarko Chinook (ATN) were conducted using COHSHK11e. The percentage of the total mortality distributions for ATN Chinook salmon among fisheries and escapement are shown in Tables 10 and 11 following the reporting format currently used by the CTC. Over 1990-2010 escapement averaged 57.1% of the total mortality (i.e., landed catch plus incidental mortality; Table 10 shows the statistics for landed catch only), with Canada Net (i.e., Terminal Central Net) having the largest impact (16.8 %) among ISBM fisheries[4], followed by Terminal Net (i.e., FNFF) with 6.2% of the total mortality and Terminal Sport with 2.4%. Canada Troll only exerts a 0.7% of the ATN total mortality. Among the AABM fisheries[5], Southeast Alaska (SEAK) Troll exerts the largest total mortality (7.9%), followed by North BC (NBC) Sport (5.8%) and NBC Troll (2.0%). The percentage of the total mortality distribution in other AABM fisheries is low, with SEAK Net at 0.2%, SEAK Sport at 0.8%, and West Coast Vancouver Island (WCVI) Troll at 0.2%. WCVI Sport does not impact ATN Chinook.

In terms of exploitation rates by brood year, there was an increase from about 31% (total exploitation rate) on brood year 1986 to approximately 60% on brood 2000, after which a second peak of similar magnitude occurred for brood 2006 (Figure 15). However, 2002 was the last complete brood (all offspring from this brood has either died, been caught or has returned to the spawner grounds). Therefore, exploitation rates for brood years 2005, 2006, and 2007 could be greater once the evaluation of these broods is completed. The embedded frame in Figure 15 shows that the incidental mortality component of total exploitation rates has increased steadily from ~3% on brood 1986 to ~11% on brood 2002.

The results of the annual exploitation rate analysis showed important variation in maturation rates of age-3, age-4, and age-5 ATN Chinook and a clear increase in the maturations rates of age-3 and age-4 fish from brood years 1986 to 1998 (Figure 16). Average maturation rates for brood years 1986-2007 were 0.0003 for age-2, 0.06 for age-3, 0.344 for age-4, 0.95 for age-5, and 1.00 for age-6. The exploitation rate analysis also produced an average ATN age-2 cohort survival rate of 2.28% (range: 0.5% – 4.9%), peaking for brood year 1991 (Figure 17). Maturation rates and survival rates were not computed for brood years 2003 and 2004 due to the suspension of the CWT release program in those years.

---

[4] The 2008 Pacific Salmon Treaty (PST) directs an Individual Stock Based Management (ISBM) fishery regime that is abundance-based and constrains to a numerical limit the total catch or the total adult equivalent mortality rate within the fisheries of a jurisdiction for a naturally spawning Chinook salmon stock or stock group. ISBM management regimes apply to all Chinook salmon fisheries subject to the PST that are not AABM fisheries.

[5] Aggregate Abundance-Based Management (AABM) fisheries include southeast Alaska sport, net, and troll (SEAK), northern British Columbia troll and Queen Charlotte Islands (NBC), and west coast Vancouver Island troll and outside sport (WCVI).

Table 10. Percent distribution of Atnarko Summer Chinook (ATN) reported catch among fisheries and escapement.

	Estimated	AABM							ISBM													
Catch	# of	SEAK			NBC		WCVI		Geo St		Canada			WA/OR coast			Puget Sound		Terminal			
Year	CWTs	Troll	Net	Sport	Troll	Sport	Troll	Sport	Troll	Sport	Troll	Net	Sport	Troll	Net	Sport	Net	Sport	Troll	Net	Sport	Esc.
1990	122	16.4%	1.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.6%	17.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	0.0%	59.8%
1991	719	5.8%	0.0%	0.0%	1.0%	1.8%	0.4%	0.0%	0.0%	0.0%	0.4%	21.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	0.8%	64.8%
1992	943	7.3%	0.0%	0.0%	1.5%	3.3%	0.3%	0.0%	0.0%	0.0%	4.6%	18.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.7%	1.8%	58.6%
1993	1292	8.7%	0.3%	0.5%	3.7%	3.3%	0.4%	0.0%	0.0%	0.0%	1.0%	13.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.3%	2.1%	64.2%
1994	1657	6.0%	0.1%	0.2%	1.3%	2.4%	0.0%	0.0%	0.0%	0.0%	2.2%	18.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	1.1%	66.2%
1995	2273	3.9%	0.0%	1.1%	0.9%	3.1%	0.0%	0.0%	0.0%	0.0%	0.3%	15.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.4%	2.6%	67.3%
1996	2001	2.4%	0.0%	0.5%	0.0%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	11.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.5%	4.4%	74.2%
1997	1142	3.9%	0.0%	1.2%	0.4%	3.2%	0.0%	0.0%	0.0%	0.0%	0.2%	9.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.5%	4.4%	69.2%
1998	1025	6.1%	0.0%	0.4%	0.0%	5.3%	0.0%	0.0%	0.0%	0.0%	0.0%	13.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.5%	2.9%	61.3%
1999	1424	5.3%	0.0%	2.4%	0.0%	3.8%	0.0%	0.0%	0.0%	0.0%	0.0%	7.2%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	3.5%	73.4%
2000	1025	6.0%	0.1%	0.0%	0.0%	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	7.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.1%	3.9%	72.2%
2001	670	5.4%	0.0%	1.3%	0.0%	2.5%	0.3%	0.0%	0.0%	0.0%	0.0%	14.5%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	9.0%	3.9%	63.0%
2002	730	4.7%	0.1%	0.5%	8.1%	4.9%	1.0%	0.0%	0.0%	0.0%	0.0%	16.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.4%	2.2%	54.2%
2003	607	4.4%	0.2%	0.0%	2.5%	13.2%	0.0%	0.0%	0.0%	0.0%	0.0%	24.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.1%	3.8%	43.7%
2004	645	8.4%	0.0%	0.0%	3.1%	8.8%	0.0%	0.0%	0.0%	0.0%	0.0%	22.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.7%	1.6%	47.4%
2005	899	12.6%	0.2%	0.8%	4.3%	14.0%	0.0%	0.0%	0.0%	0.0%	0.0%	16.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.3%	2.0%	42.5%
2006	1404	8.4%	0.0%	1.1%	2.2%	7.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.4%	2.3%	65.7%
2007	391	10.5%	0.0%	2.3%	1.0%	7.4%	0.5%	0.0%	0.0%	0.0%	0.0%	17.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.4%	2.3%	52.4%
2008	138	0.7%	0.0%	2.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	0.0%	82.6%
2009	672	7.1%	0.0%	0.0%	2.4%	5.1%	0.0%	0.0%	0.0%	0.0%	0.0%	22.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	13.7%	2.4%	46.4%
2010	776	9.8%	0.1%	0.6%	2.6%	8.1%	0.0%	0.0%	0.0%	0.0%	0.0%	13.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.4%	1.3%	53.7%
1979-2010	979	6.8%	0.1%	0.7%	1.7%	4.8%	0.1%	0.0%	0.0%	0.0%	0.5%	15.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.5%	2.3%	61.1%
1979-1984	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1985-1995	1168	8.0%	0.3%	0.3%	1.4%	2.3%	0.2%	0.0%	0.0%	0.0%	1.7%	17.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.4%	1.4%	63.5%
1996-1998	1389	4.1%	0.0%	0.7%	0.1%	3.3%	0.0%	0.0%	0.0%	0.0%	0.1%	11.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.2%	3.9%	68.2%
1999-2010	782	6.9%	0.1%	0.9%	2.2%	6.5%	0.1%	0.0%	0.0%	0.0%	0.0%	15.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.7%	2.4%	58.1%

SEAK: South East Alaska
NBC: Northern British Columbia
WCVI: West Coast Vancouver Island
Geo St: Georgia Strait
WA/OR: Washington/Oregon

Table 11. Percent distribution of Atnarko Summer Chinook (ATN) total fishing mortalities among fisheries and escapement.

Catch Year	Estimated # of CWTs	AABM SEAK Troll	AABM SEAK Net	AABM SEAK Sport	AABM NBC Troll	AABM NBC Sport	AABM WCVI Troll	AABM WCVI Sport	ISBM Geo St Troll	ISBM Geo St Sport	ISBM Canada Troll	ISBM Canada Net	ISBM Canada Sport	ISBM WA/OR coast Troll	ISBM WA/OR coast Net	ISBM WA/OR coast Sport	ISBM Puget Sound Net	ISBM Puget Sound Sport	ISBM Terminal Troll	ISBM Terminal Net	ISBM Terminal Sport	Esc.
1990	143	20.3%	3.5%	0.0%	1.4%	1.4%	0.7%	0.0%	0.0%	0.0%	4.2%	14.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.8%	0.0%	51.0%
1991	751	7.7%	0.1%	0.0%	1.7%	2.3%	0.4%	0.0%	0.0%	0.0%	0.9%	20.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.3%	0.8%	62.1%
1992	982	8.9%	0.0%	0.0%	1.8%	3.7%	0.3%	0.0%	0.0%	0.0%	5.3%	18.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.7%	1.8%	56.3%
1993	1359	10.6%	0.7%	0.6%	4.6%	3.6%	0.4%	0.0%	0.0%	0.0%	1.2%	13.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	2.1%	61.1%
1994	1710	7.5%	0.1%	0.3%	1.5%	2.5%	0.0%	0.0%	0.0%	0.0%	2.6%	17.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	1.2%	64.2%
1995	2406	4.4%	0.1%	1.1%	1.1%	3.5%	0.0%	0.0%	0.0%	0.0%	0.3%	18.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.2%	2.6%	63.6%
1996	2078	2.6%	0.0%	0.5%	0.2%	1.7%	0.0%	0.0%	0.0%	0.0%	0.0%	13.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.3%	4.5%	71.5%
1997	1194	4.4%	0.0%	1.5%	0.4%	4.1%	0.0%	0.0%	0.0%	0.0%	0.2%	10.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.2%	4.4%	66.2%
1998	1088	7.1%	0.0%	0.5%	0.0%	6.3%	0.0%	0.0%	0.0%	0.0%	0.0%	15.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.1%	2.9%	57.7%
1999	1461	5.8%	0.0%	2.5%	0.0%	4.4%	0.0%	0.0%	0.0%	0.0%	0.0%	7.7%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	4.2%	3.6%	71.5%
2000	1052	6.5%	0.1%	0.0%	0.0%	3.5%	0.0%	0.0%	0.0%	0.0%	0.0%	7.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.0%	4.1%	70.3%
2001	715	6.6%	0.0%	1.5%	0.0%	3.1%	0.4%	0.0%	0.0%	0.0%	0.0%	16.6%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	8.7%	3.9%	59.0%
2002	779	5.0%	0.1%	0.5%	8.7%	6.0%	0.9%	0.0%	0.0%	0.0%	0.0%	18.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.1%	2.2%	50.8%
2003	676	4.6%	0.1%	0.0%	2.7%	16.1%	0.0%	0.0%	0.0%	0.0%	0.0%	26.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.4%	3.7%	39.2%
2004	712	9.6%	0.0%	0.0%	3.5%	11.4%	0.0%	0.0%	0.0%	0.0%	0.0%	23.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	8.0%	1.5%	43.0%
2005	972	12.6%	0.2%	0.8%	4.4%	16.0%	0.0%	0.0%	0.0%	0.0%	0.0%	17.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.9%	2.0%	39.3%
2006	1460	8.5%	0.0%	1.1%	2.2%	7.8%	0.0%	0.0%	0.0%	0.0%	0.0%	10.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.3%	2.3%	63.2%
2007	469	10.2%	0.0%	2.1%	1.1%	8.1%	0.4%	0.0%	0.0%	0.0%	0.0%	26.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	5.3%	2.1%	43.7%
2008	153	5.9%	0.0%	2.6%	1.3%	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	9.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.6%	0.0%	74.5%
2009	791	7.1%	0.0%	0.0%	2.3%	5.2%	0.0%	0.0%	0.0%	0.0%	0.0%	32.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	11.8%	2.1%	39.4%
2010	808	10.0%	0.1%	0.6%	2.7%	9.5%	0.0%	0.0%	0.0%	0.0%	0.0%	13.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	10.1%	1.4%	51.6%
1979-2010	1036	7.9%	0.2%	0.8%	2.0%	5.8%	0.2%	0.0%	0.0%	0.0%	0.7%	16.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	6.2%	2.4%	57.1%
1979-1984	0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
1985-1995	1225	9.9%	0.8%	0.3%	2.0%	2.8%	0.3%	0.0%	0.0%	0.0%	2.4%	17.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.2%	1.4%	59.7%
1996-1998	1453	4.7%	0.0%	0.8%	0.2%	4.0%	0.0%	0.0%	0.0%	0.0%	0.1%	13.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.9%	4.0%	65.1%
1999-2010	837	7.7%	0.1%	1.0%	2.4%	7.7%	0.1%	0.0%	0.0%	0.0%	0.0%	17.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	7.2%	2.4%	53.8%

SEAK: South East Alaska
NBC: Northern British Columbia
WCVI: West Coast Vancouver Island
Geo St: Georgia Strait
WA/OR: Washington/Oregon

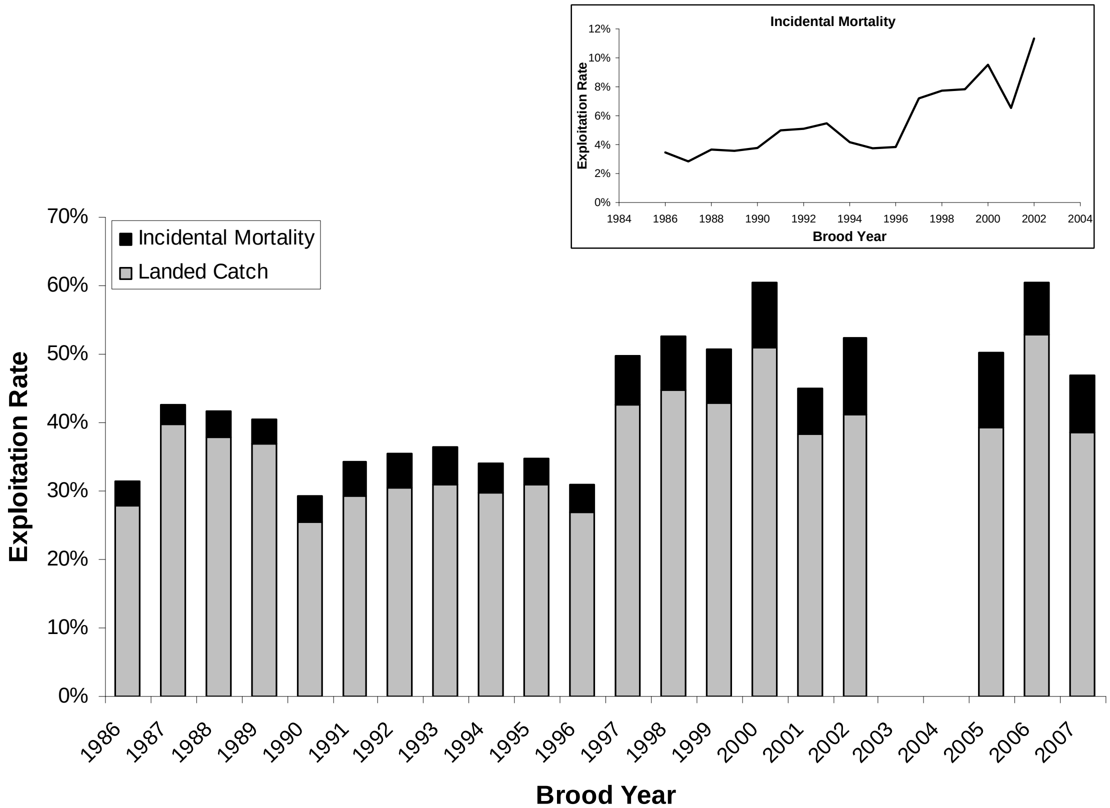


Figure 15. Atnarko Chinook (ATN) total exploitation rate by brood year (in adult equivalents). Complete broods: 1986-2002. There were no releases in 2003 and 2004.

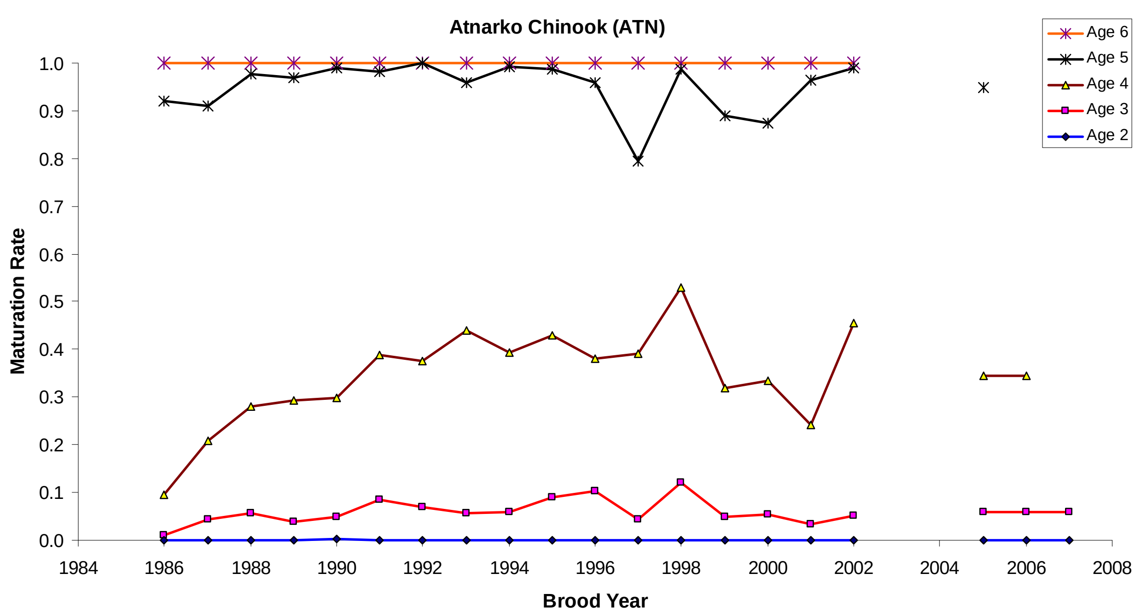


Figure 16. Maturation rates of Atnarko Chinook (ATN). Complete broods: 1986 to 2002. There were no releases in 2003 and 2004.

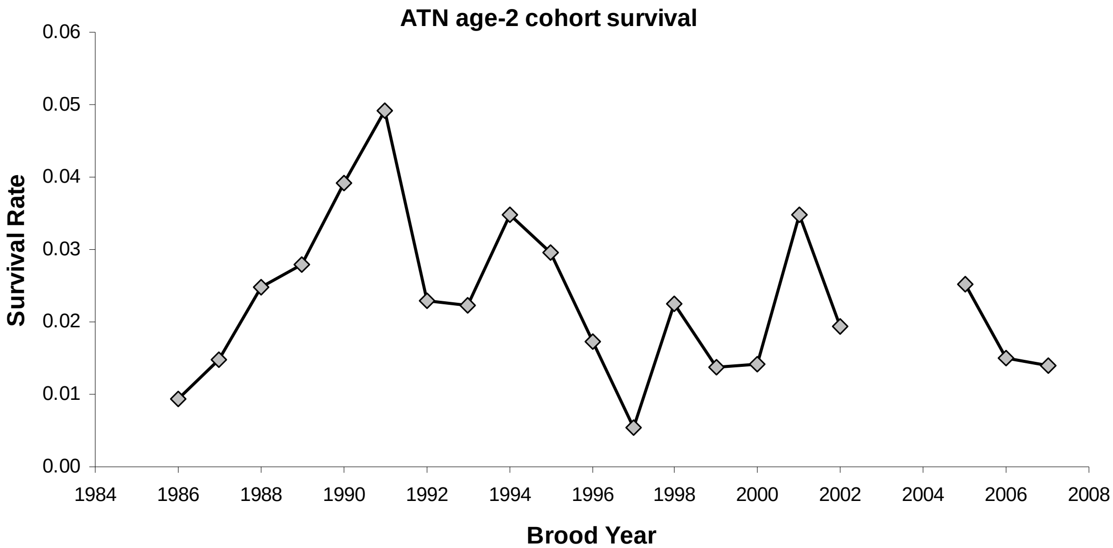


Figure 17. Age-2 cohort survival rates of Atnarko Chinook (ATN) for brood years 1986 to 2007. Complete broods: 1986-2005. There were no releases in 2003 and 2004.

The age-2 cohort survival rate for the base period (1979-1982) produced by the escapement procedure and the OOB procedure were similar (3.24% vs. 3.75%, respectively) and higher than the average for brood years contributing to recovery years 1990-2010 (Tables 12 and 13). Although there is no apparent trend in age-2 cohort survival rates, only survival rates of broods 1990 and 1991 were higher than the average base-period survival rate. The execution of COSHAK4 also produced maturation rates that were substantially different than the average rates across brood years 1986-2007. The results of the COSHAK4 analysis following the OOB procedure indicated that both, maturation rates and adult equivalents for the maximum age (age-6 fish) did not reach the 100% expected for the maximum age (Table 13).

Important differences in the relative magnitudes of harvest rates exerted by fishing sectors (troll, net, and sport) and across regions (ocean vs. terminal fisheries) were obvious between the output produced by COSHAK4 using the escapement procedure (Table 12) and the output produced by COSHAK4 following the OOB procedure (Table 13). The former indicates troll fisheries had greater harvest than either net or sport fisheries and that ocean fisheries exerted greater harvest rates than terminal fisheries in the base period. Conversely, the output of the OOB procedure indicates net fisheries had greater harvest rate than either troll or sport and that terminal fisheries had a greater harvest rate than ocean fisheries in the base period. In terms of total harvest rates, OOB procedure produced a base period harvest rate (67.18%) that was greater than the one produced by the escapement procedure (46.21%). The clear identification of a best approach to generate base-period data (escapement procedure vs. OOB procedure) for ATN Chinook salmon may be possible only after the MDL files produced by COSHAK4 (see Appendices I and J) are used to run a PSC Chinook Model calibration, and after those results are examined for anomalies. However, there is evidence that the larger harvest rates in net fisheries, and therefore in terminal fisheries, produced by the OOB procedure are the result of using brood year tag codes (1987-1990) with high levels of Terminal Central Net recoveries as shown in Figure 10. The extremely small number of Terminal Central Net recoveries in base period years is deemed as the main cause of the lower harvest rates in net fisheries, and therefore terminal fisheries, in the cohort analysis using the escapement procedure in COSHAK4. Hence, the fact that the OOB procedure produced (i) a total harvest rate that is substantially greater (67%) than the 43% average total mortality distribution during 1990-2010 (see Table 11), (ii) atypical maturation rates and adult equivalents (Table 13), and (iii) net and ocean harvest rates representative of high levels of Terminal Central Net recoveries, are deemed as strong reasons to favour the outcome of the cohort analysis executed with the escapement procedure.

Table 12. Results of the base-period cohort analysis using the escapement option (i.e., escapement procedure) in COSHAK4.

Brood year	Tag codes	CWT	Production
1976	02/20/16	45730	53223
1976	02/20/17	2715	3159
1976	02/20/18	2649	3082
1977	02/20/20	9316	9316
1977	02/20/21	5490	5490
1977	02/20/22	57654	57654
1978	02/17/32	79761	79761

	Cohort	Maturation rates	Adult equivalents	Age-2 cohort survival
AGE 6	141.9	1.0000	1.0000	0.032
AGE 5	1334.8	0.8403	0.9840	
AGE 4	2538.8	0.2855	0.9183	
AGE 3	3994.6	0.0531	0.7487	
AGE 2	6854.9	0.0065	0.5272	

SIMPLE HARVEST RATE/ALL FISHERIES AND AGES:

	W/O SHAKERS	WITH SHAKER
TROLL	0.2573	0.2735
NET	0.1393	0.1415
SPORT	0.0442	0.0471
OCEAN	0.3199	0.3427
TERMINAL	0.1778	0.1816
TOTAL	0.4408	0.4621
OCN/ADT EQV	0.2991	0.3152
TTL/ADT EQV	0.4237	0.4396

Table 13. Results of the base-period cohort analysis using the out-of-base procedure in COSHAK4.

Brood year	Tag codes	CWT	Production
1987	02/54/46	25118	851581
1987	02/54/47	26259	52427
1987	02/54/48	27288	54357
1987	02/55/52	75514	1002158
1988	02/59/56	27143	915395
1988	02/59/57	25595	50169
1988	02/59/58	26470	49118
1988	02/59/59	27549	331697
1988	02/59/60	27406	330003
1988	02/59/61	25092	303971
1989	02/02/46	24544	370086
1989	02/02/47	23906	360467
1989	02/02/48	24174	364507
1989	02/02/49	25310	330296
1989	02/02/50	24780	324250
1989	02/02/51	25012	326407
1990	02/14/28	23746	366651
1990	02/14/29	22532	349283
1990	02/14/30	24576	379467
1990	02/15/21	22021	354945
1990	02/15/22	25368	405317
1990	02/15/23	18955	309014

	Cohort	Maturation rates	Adult equivalents	Age-2 cohort survival
AGE 6	359.5	0.9747	0.9858	0.0375
AGE 5	4698.2	0.8844	0.9747	
AGE 4	8943.2	0.2500	0.9154	
AGE 3	13436.1	0.0443	0.7442	
AGE 2	22458.7	0.0008	0.5213	

SIMPLE HARVEST RATE/ALL FISHERIES AND AGES:

	W/O SHAKERS	<WITH SHAKERS>
TROLL	0.2161	0.2239
NET	0.4174	0.4170
SPORT	0.0289	0.0309
OCEAN	0.2329	0.2427
TERMINAL	0.5599	0.5666
TOTAL	0.6624	0.6718
OCN/ADT EQV	0.2224	0.2307
TTL/ADT EQV	0.6578	0.6666

3.3. Some comparisons between ATN and CWT indicators KLM and QUI

As a corollary to previous analyses, ATN's time series of escapement, estimated CWT recoveries, mortality percent distribution across fisheries, maturation rates, and survival rates were compared to those of neighbour CWT Chinook indicator stocks Kitsumkalum (KLM) and Quinsam (QUI). Escapement data for KLM and QUI were extracted from PSC (2010), while mortality percent distribution across fisheries, maturation rates, and survival rates for these stocks were drawn from the most recent calibration of the PSC Chinook Model (Clb1106). The magnitude of ATN escapement was consistently greater than the escapement in KLM or QUI from 1991 to 2000, after which KLM escapement was greater than ATN escapement for most years in the last decade (Figure 18). Escapement in QUI has been consistently the lowest among these three Chinook salmon stocks for the last two decades. In addition, no covariation was observed between ATN and KLM (r = -0.21) or ATN and QUI (r = -0.35), but escapement in KLM and QUI has been correlated in the last two decades (r = 0.66). Although escapement trends are not strongly apparent for any of these stocks, ATN shows a declining tendency with a peak of 35,000 in 1993 and a low of 9,000 in 2008. Estimated escapement in 2010 (not shown in Figure 18) was similar to that of 2009 (~ 11,000 fish).

Estimated CWT recoveries by brood year have been greater in ATN than either KLM or QUI for most of the broods from 1985 to 2005. ATN recoveries were particularly high for brood year 1991 (Figure 19). The same pattern took place for estimated CWT recoveries in fisheries (terminal and pre-terminal pooled; Figure 20), with ATN recoveries from brood year 1991 being also particularly high. ATN recoveries for years 2003 and 2004 in these figures are zero due to the lack of CWT releases representing those broods.

A comparison of the total mortality percent distributions between ATN and KLM and QUI showed that in 1985-1995 SEAK Troll and Canada Net were the fisheries causing the greatest mortality in these three stocks (Figure 21). However, relative mortality distributions changed in 1999-2009 still indicating SEAK Troll and Canada Net having the largest impact in ATN but not so in KLM and QUI, which still experienced substantial impacts from SEAK Troll but low impacts from Canada Net. Another important change in the average total mortality distributions for 1999-2009, relative to 1985-1995, was a substantial increase in the percentage of ATN mortalities in the Terminal Net and NBC Sport fisheries. For the NBC troll fishery, the average percentage of the total mortality distribution decreased from 1985-1995 to 1999-2009 for QUI and KLM, however ATN was unchanged. Among these three stocks, QUI is the only one impacted by the Georgia Strait Sport fishery, whereas Terminal Net is only important for ATN, and KLM is the only stock experiencing increased mortality from NBC Sport during 1999-2009 relative to 1985-1995 (Figure 21).

Important differences in base period maturation rates exist between KLM and both, QUI and ATN, which show similar patterns (Figure 22). The different pattern shown by KLM is mainly due to its stream-type life history and older age-at maturity; QUI and ATN mostly exhibit ocean-type life histories. Nonetheless, different age-4 maturation rates between ATN and QUI become obvious in more recent years (1986-2003), with QUI showing a maturation rate (0.56) substantially greater than that of ATN (0.34). Important differences also exist in terms of survival rates, with ATN showing higher survival rates than either QUI or KLM for the majority of complete brood years (1986-2002) shown in Figure 23. Interestingly, ATN age-2 cohort survival is strongly and negatively correlated with survival rates in KLM (r = -0.62) and QUI (r = -0.92). Although a recent study showed that Pacific Northwest Chinook survival covaries on a spatial scale of 350-450 km (Sharma et al. 2011), there is no apparent ecological mechanism explaining a negative correlation. However, the strong signals may warrant further investigation.

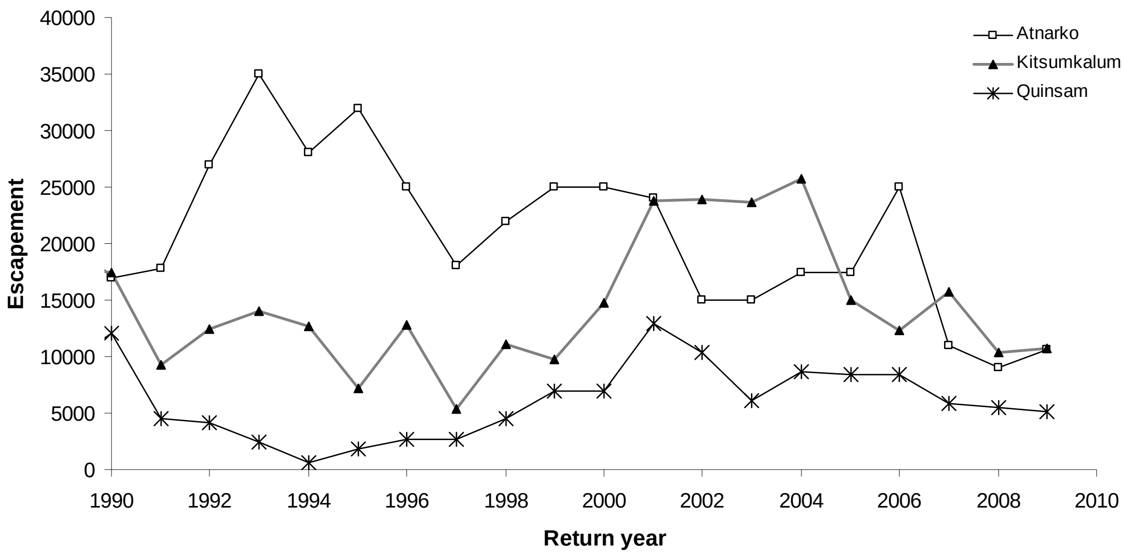


Figure 18. Escapement time series for Atnarko Chinook (ATN) and CWT Chinook indicator stocks Quinsam (QUI) and Kitsumkalum (KLM).

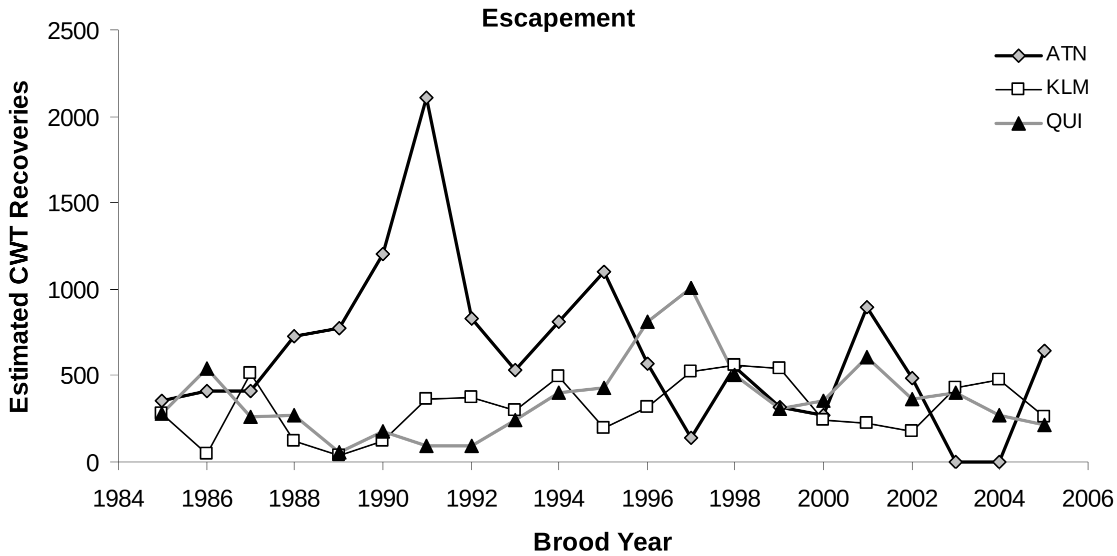


Figure 19. Estimated CWT recoveries by brood year in the escapement for Atnarko Chinook (ATN) and CWT Chinook indicator stocks Kitsumkalum (KLM) and Quinsam (QUI).

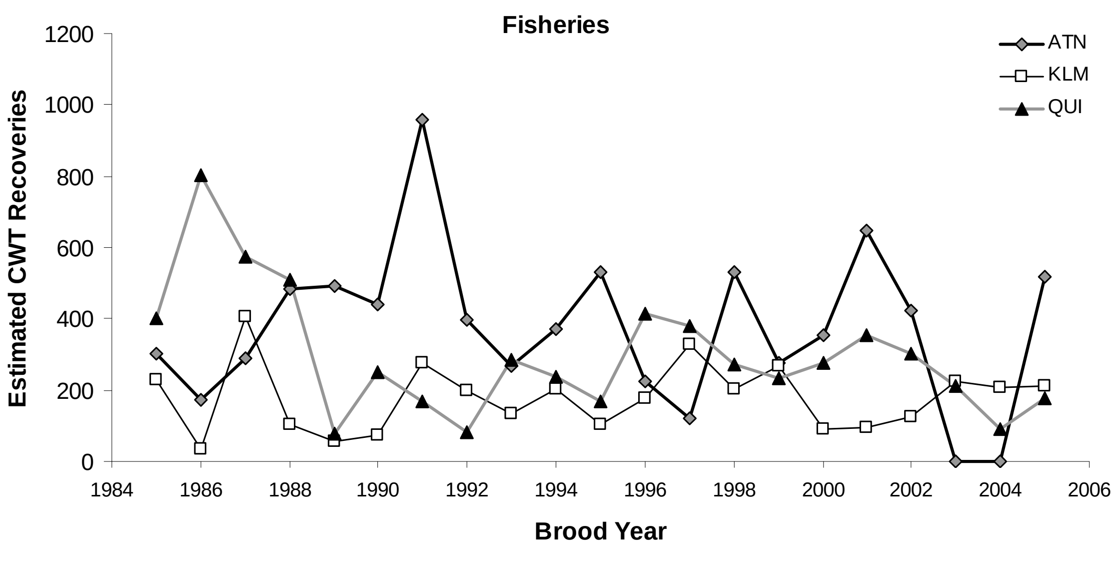


Figure 20. Estimated CWT recoveries by brood year in fisheries (terminal and pre-terminal pooled) for Atnarko Chinook (ATN) and CWT Chinook indicator stocks Kitsumkalum (KLM) and Quinsam (QUI).

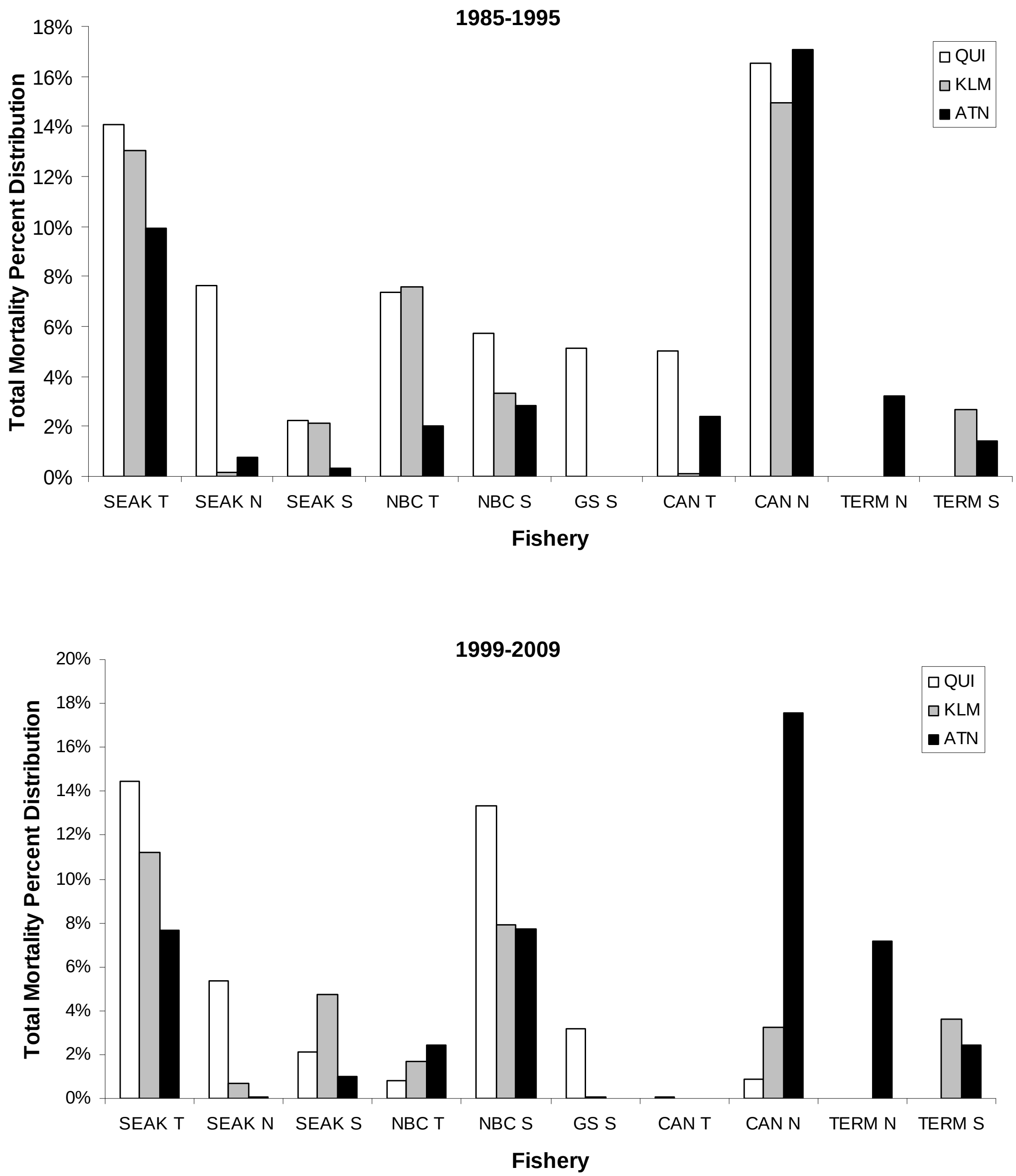


Figure 21. Comparison of average total mortality percent distributions (only the ten most important fisheries are shown) between Atnarko Chinook (ATN) and CWT Chinook indicator stocks Quinsam (QUI) and Kitsumkalum (KLM) for two time periods. Fisheries represented are: South East Alaska Troll, Net, and Sport (SEAK T, SEAK N, and SEAK S, respectively), Northern British Columbia Troll and Sport (NBC T and NBCS, respectively), Georgia Strait Sport (GS S), Central BC Troll and Net (CAN T and CAN N, respectively), and Terminal Net and Sport (TERM N and TERM S, respectively).

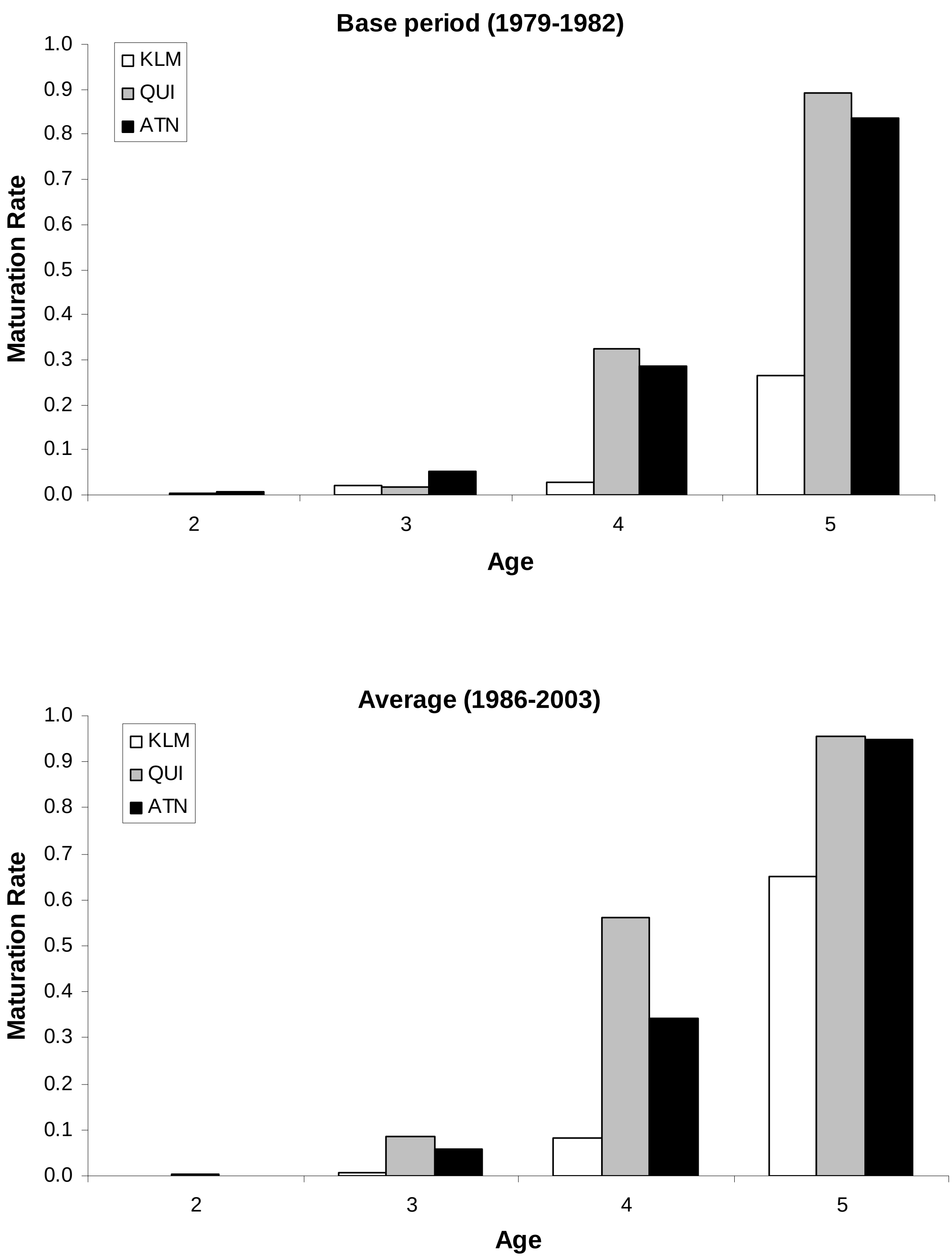


Figure 22. Comparison of maturation rates between Atnarko Chinook (ATN) and CWT Chinook indicator stocks Kitsumkalum (KLM) and Quinsam (QUI) for two time periods. ATN base period maturation rates correspond to those in Table 12.

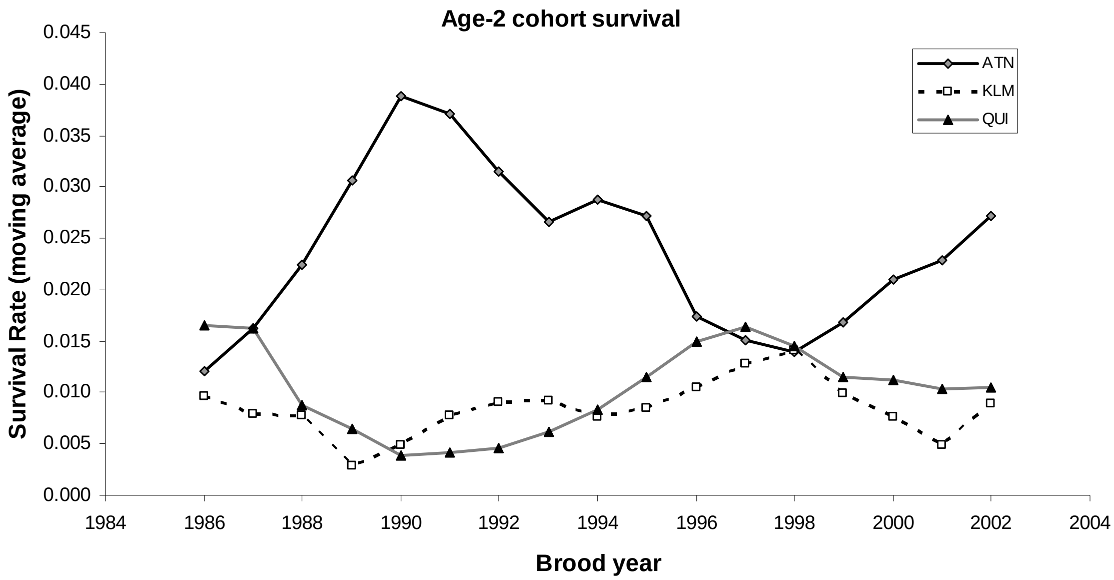


Figure 23. Comparison of age-2 cohort survival rates between Atnarko Chinook (ATN) and CWT Chinook indicator stocks Kitsumkalum (KLM) and Quinsam (QUI) for complete brood years 1986-2002. Time series were smoothed using a 3-year symmetric moving average.

4. DISCUSSION

The importance of this investigation resides in the preparation of reliable CWT data and the generation of crucial information about the exploitation history of Atnarko Chinook salmon. These two processes are expected to facilitate ATN's incorporation as an exploitation rate indicator stock in future PSC assessments and make possible a refinement of the stocks used in the PSC Chinook Model. The inclusion of this stock responds to the need identified by the PSC's CWT workgroup for an appropriate indicator of the biological and fishery characteristics of Chinook salmon stocks entering the central coast area of BC. Although significant effort had been placed on maintaining Atnarko Chinook escapement estimation procedures and CWT release and recovery programs, only now have escapement estimates been validated and missing data for freshwater CWT recoveries been addressed to allow successful cohort analyses. The continuation of the 5-year CWT Improvement Program initiated in 2009 is expected to provide additional high-quality data that will eventually improve the statistical and estimation properties of the various components entailed by the cohort analyses.

Significant differences in escapement trajectories, life history traits and exploitation patterns (in addition to genetic factors; Holtby and Ciruna 2007) between Chinook salmon in the Atnarko River and those in the Kitsumkalum and Quinsam rivers stresses the importance of having a Chinook salmon stock representative of the central coast of BC that can be incorporated in coastwide and regional assessments of Chinook salmon populations. DFO's enhancement and CWT programs by the Snootli Creek Hatchery are the most intensive Chinook salmon assessments in central British Columbia, and have produced large numbers of CWT recoveries in fisheries and escapement, thus enabling the generation of important population statistics via cohort analyses. Substantial improvements can be achieved by exercising a more ambitious monitoring of commercial, First Nations, and sport fishery catches, therefore allowing direct accounting of CWT recoveries in the commercial net fishery and sampling fractions in the First Nations and sport fisheries. For example, a recent initiative in the central coast of BC (PFMAs 7-9) aims to collect stratified mark-rate data as well as comprehensive estimates of catch for the sport fishery (Personal communication; Julian Sturhahn, Fisheries and Oceans Canada Campbell River, BC). These data are required by DFO's Mark Recovery Program to estimate total CWT encounters and subsequent stock specific harvest impacts. In the absence of these data, the program currently uses CWT submission rates from other areas (global pooling) to expand the observed CWT recoveries. This approach can lead to misrepresentation of sport fishery harvest impacts. In turn, improvements in CWT recovery data should eliminate the necessity for global pooling and any biases associated with this method. In this study, several indirect methods were necessary to address missing data, and these methods can be improved with additional information. However, direct observations and sampling should be used when possible.

Escapement calibration methods in the Atnarko will be revisited at the end of the 5-year CWT program (2013) when additional escapement estimates derived from mark-recapture studies will be used to re-validate and re-calibrate escapement estimates for the 1990-2013 time series. This additional data, together with the derivation of more accurate sampling fractions for First Nations and sport catches, is expected to improve the accuracy of expansion factors and therefore the CWT recovery summaries used for cohort analyses. The great similarity of escapement estimates between the 3M Average and the Petersen in years with mark-recapture studies validated the 3M Average method and prompted the deferral for using the results of a linear model to calibrate the time series. However, the use of the latter method could be acceptable in the future if greater statistical inference is facilitated by more years of data with greater contrast, or if the relationship between the 3M Average and the Petersen estimator deteriorates.

Contrary to most Canadian exploitation rate indicator stocks (Kitsumkalum Summers, Robertson Creek Falls, Quinsam Falls, Puntledge Summers, Big Qualicum Falls, Cowichan Falls, and Chilliwack Falls) that show declining exploitation rates on brood years 1986-2003 (PSC 2009), cohort analyses indicate total exploitation rates of Atnarko Chinook Summers increased from 0.31 to 0.52 on those brood years. Only Kitsumkalum Falls shows similar levels of total exploitation rates across brood years, and although Cowichan Falls experienced sharp declines from brood year 1987 to brood year 1995, total exploitation rates on this stock have increased steadily since then up to approximately 70%. This study indicates the ocean fishery with the greatest impact on Atnarko Chinook Summers is SEAK Troll with a 44.9% of the average total fishing mortality by ocean fisheries only during 1990-2010, followed by NBC Sport with 33.0%, and NBC Troll with 11.3%. Other fisheries contributing at lower levels are SEAK Sport (4.4%), Canada Troll (i.e. troll fisheries in central BC; 4.0%), SEAK Net (1.4%), and WCVI Troll (1.0%). No fishing mortality on Atnarko Chinook Summers has occurred from the Canada Troll fishery since 1998.

In terms of recreation of base period data, greater reliability was attributed to the method using model-based escapement pseudo-recoveries in COSHAK4 to generate a base-period cohort analysis (i.e., escapement procedure) than to the OOB procedure due to the uncertainty associated to fishery scalars used by this approach in addition to the issues described in Section 3.2: (i) larger than expected total harvest rate; (ii) atypical maturation rates and adult equivalents generated by this procedure; and, (iii) large differences in Terminal Central Net CWT recoveries between the base period and the out-of-base period. In addition, algorithm limitations requiring further investigation have been recently identified in the OOB procedure. However, until MDL files are incorporated in a PSC Chinook Model run and coastwide responses are analyzed for anomalies, it will remain inconclusive what procedure generates the best output. This appraisal should be considered by the CTC in future calibrations of the PSC Chinook Model.

5. ACKNOWLEDGEMENTS

The authors wish to thank Wayne Levesque for his help coordinating communications between DFO Science and Snootli Creek Hatchery. Thanks also to Matt Mortimer for providing archival Atnarko Chinook data. We are thankful to Ryan Briscoe for his insights on analytical aspects and coding details of the cohort analysis programs used in this investigation. Our appreciation goes also to John Carlile for useful discussions about the out-of-base cohort analysis procedure. Nick Komick and John Bao had a valuable contribution to this project by helping in the development of automation frameworks to extract and modify CWT recovery data. Thanks to Ivan Winther, Julian Sturhahn, and Nick Komick for their comments and suggestions on a previous version of the report. Geoff Mullins provided maps indicating river segments and Chinook upstream distribution in the Atnarko. We would like to thank the field and station crews of the Snootli Creek Hatchery and Bella Coola management staff for their cooperation and extensive effort into developing the field surveys necessary for escapement estimation and maintaining the CWT release and recovery programs. Current Atnarko Chinook programs such as enhancement of yearling fish, CWT application, mark-recapture studies, and catch sampling in commercial, First Nations and sport fisheries are possible thanks to PSC funding through its Northern Endowment Fund and CWT Improvement Fund.

6. REFERENCES CITED

Andrew, J.H., Sutherland, G.H., and Webb, T.M. 1988. Abundance, age, size, sex and coded wire tag recoveries for Chinook salmon escapements of Atnarko River, 1984-1986. Can. Manuscr. Rep. Fish. Aquat. Sci. 2014: 87 p.

Anon. 2001. Salmon conservation in the Central Coast. Pacific Fisheries Resource Conservation Council.: 52 p.

BCWCS. 2007. Bella Coola watershed –based Fish Sustainability Plan Stage II. Bella Coola Watershed Conservation Society. Prepared for Communities of Bella Coola Valley and Fisheries and Oceans Canada. January 2007. 112 p.

DFO. 1986. Pacific region salmon stock management plan, Volume F, Statistical area 8. Department of Fisheries and Oceans. 55p.

DFO. 2002. 2001 Post season review and 2002 planning framework, Salmon, Central Coast, Areas 7 to 10. Fisheries and Oceans Canada. 99 p.

DFO. 2009. Snootli Creek Hatchery Chinook augmentation: brood years 2007 and 2008. Prepared for the Pacific Salmon Commission. Fisheries and Oceans Canada. 20 p.

English, K.K., Bocking, R.C., and Irvine, J.R. 1992. A robust procedure for estimating salmon escapement based on the area-under-the-curve method. Can. J. Fish. Aquat. Sci. 49: 1982.

Healey, M.C. 1991. The life history of Chinook salmon (*Oncorhynchus tshawytscha*). Pages 311-393 in C. Groot and L. Margolis, editors. Pacific salmon life histories. UBC Press Vancouver.

Hilland, R.T., and Lehman, S. 2005. Snootli Creek Hatchery production review (Draft). Report for Fisheries and Oceans Canada.

Holtby, L.B., and Ciruna, A. 2007. Conservation Units for Pacific salmon under the Wild Salmon Policy. Canadian Science Advisory Secretariat, Research Document 2007/070. Fisheries and Oceans Canada, Vancouver, BC.

Kuhn, B.R. 1988. The MRP-Reporter Program: a data extraction and reporting toll for the Mark Recovery Program Database. Can. Tech. Rep. Fish. Aquat. Sci. 1625.

Lassen, H., and Medley, P. 2001. Virtual Population Analysis: A practical manual for stock assessment. FAO Fisheries Technical Paper No. 400. Rome, Italy. 129 p.

McNicol, R.E. 1999. An assessment of Kitsumkalum River summer Chinook, a north coast indicator stock. Canadian Stock Assessment Secretariat Research Document 99/164. Fisheries and Oceans Canada, Vancouver, BC.

Parken, C.K., R.E. Bailey, and J.R. Irvine. 2003. Incorporating uncertainty into area-under-the-curve and peak count salmon escapement estimation. North American Journal of Fisheries Management 23:78-90.

Pestal, G.P. 2004. Simple decision guidelines for terminal fisheries targeting Atnarko River, British Columbia Chinook salmon (*Oncorhynchus tshawytscha*). M.Sc. Thesis, Simon Fraser University, Burnaby, BC.

Pitre, K.R. 1991. Estimation of Atnarko River Chinook escapements and hatchery contributions. Memorandum, Government of Canada, July 22, 1991.

PSC. 1988. 1987 Annual Report. Pacific Salmon Commission, Report TCCHINOOK (88)-2. Vancouver, British Columbia, Canada.

PSC. 1997. Incidental Fishing Mortality of Chinook Salmon: Mortality Rates Applicable to Pacific Salmon Commission Fisheries. Pacific Salmon Commission Report TCCHINOOK (97)-1. Vancouver, British Columbia, Canada.

PSC. 2008. An action plan in response to Coded Wire Tag (CWT) Expert Panel Recommendations. A Report of the Pacific Salmon Commission CWT Workgroup. Pacific Salmon Comm. Tech. Rep. No. 25: 170 p.

PSC. 2009. 2009 Annual Report of the Exploitation Rate Analysis and Model Calibration. Pacific Salmon Commission Report TCCHINOOK (09)-3. Vancouver, British Columbia, Canada.

PSC. 2010. 2010 Annual Report of Catches and Escapements. Pacific Salmon Commission, Report TCCHINOOK (10)-1. Vancouver, British Columbia, Canada.

Riddell, B. 2004. Pacific salmon resources in Central and North Coast British Columbia. Pacific Fisheries Resource Conservation Council. February 2004. 156 p.

Sharma, R., Vélez-Espino, L.A., Wertheimer, A.C., Mantua, N., and Francis, R.C. 2011. Relating spatial and temporal scales of climate and ocean variability to survival of Pacific Northwest Chinook. *Submitted* (June 28, 2011). Fisheries Oceanography.

Slaney, T.L. 1986. Chinook keystream program on the Atnarko River. Aquatic Resources Limited, Vancouver, BC. Report prepared for the Department of Fisheries and Oceans, December 1986. 52 p.

Sturhahn, J. 2009. Atnarko River Chinook Escapement Estimation Project-Central B.C. Prepared for the Pacific Salmon Commission Chinook Salmon Sentinel Stocks Program. Unpublished. 13 p.

Vélez-Espino, L.A., Mullins, G., Willis, J., Krimmer, A., and Levesque, W. 2010. Mark-recapture experiment for the 2009 Chinook salmon spawning escapement in the Atnarko River. Can. Manuscr. Rep. Fish. Aquat. Sci. 2930: xii + 51 p.

7. APPENDICES

Appendix A. Estimated Atnarko Chinook (ATN and ATS) CWT recoveries by age and tag code for Terminal Net (FNFF), Terminal Sport, and Escapement. Age-7 fish in the escapement was added to age-6 (only one case: tag code 025957). This table includes non-indicator tag codes*.

Tagcode	Term N 2	Term N 3	Term N 4	Term N 5	Term N 6	Term S 2	Term S 3	Term S 4	Term S 5	Term S 6	Esc 2	Esc 3	Esc 4	Esc 5	Esc 6
02-02-46			2.31	3.63								14.33	61.37	48.51	
02-02-47			3.47	4.84								4.44	52.45	45.51	1.00
02-02-48			1.16	2.42								5.44	49.37	74.15	1.00
02-02-49			5.78	6.05									27.08	101.94	
02-02-50			2.31	4.84									47.99	118.73	1.00
02-02-51	1.24		2.31	1.21	2.33					3.05			35.99	87.15	
02-02-52			1.21		2.33										
02-03-46				10.47	1.13				3.05				12.86	68.38	36.22
02-14-28				11.63					3.05			12.00	31.65	114.37	
02-14-29			1.21	10.47					9.15			10.97	83.01	168.56	
02-14-30			2.42	9.30								32.91	57.36	152.16	
02-15-21			3.63	9.30								5.49	118.66	99.98	
02-15-22				8.14					9.15			10.97	44.51	79.58	
02-15-23			1.21	10.47	1.13							16.46	71.22	97.98	
02-32-57					2.44										9.41
02-32-58															9.41
02-32-59															4.71
02-32-60					1.22										6.71
02-36-41				8.53	1.24				3.95					56.77	
02-36-42				4.87					1.98					48.36	1.00
02-36-43				3.65										28.53	
02-36-44				7.31					1.98					46.36	2.00
02-37-50				4.87					1.98					43.36	2.00
02-37-51				3.65										31.24	7.82
02-37-52									1.98					23.83	6.82
02-37-53				4.87	1.24									60.48	1.00
02-43-49			1.22										4.00	29.30	
02-43-50			1.22	4.95					2.49				16.12	23.47	
02-43-51				3.71									4.71	41.94	1.00
02-43-52				3.71										65.42	
02-43-53				1.24					2.49				9.41	52.77	4.44
02-43-54				1.24					2.49					70.24	
02-43-55														18.65	13.33
02-43-56				1.24									9.41	36.12	8.89
02-54-46			1.24										2.00	47.43	1.03
02-54-47				2.64									7.82	49.43	
02-54-48		1.22	2.48	1.32	1.16							4.71	29.30	75.09	
02-55-52		1.22	2.48	13.18								23.53	41.12	12.00	115.24
02-59-56		1.24	3.95								1.00	27.30	24.21	107.97	
02-59-57			2.64	2.31								1.00	46.43	64.45	9.20
02-59-58			2.64	3.47								6.82	28.66	65.82	
02-59-59			3.95	1.16									50.87	94.28	
02-59-60				4.63									25.21	69.93	
02-59-61		2.48	3.95	2.31								13.65	47.43	49.37	
02-60-01			1.32												
18-01-64												1.07			
18-01-66		1.41										1.07			
18-02-74		1.41													
18-02-78												13.19			
18-03-25			2.33	23.73	4.95				19.34	6.98		5.93	45.99	367.07	3.00
18-03-54		1.21	25.59	29.38				9.15	29.01			110.73	421.70	547.58	1.00
18-08-26		3.63	23.26	19.21				9.15	14.50			32.65	124.57	275.69	9.86
18-08-27		1.21	11.63	24.86	1.24			9.15	19.34			60.29	209.35	305.96	10.86
18-08-37		1.21	5.81	13.56				3.05	4.83						
18-09-07			3.39	9.91	1.18			14.50	6.98		5.93		24.31	81.88	9.73
18-09-08				8.67	1.18			4.83			11.86		15.13	127.32	9.73
18-12-22			12.43	16.10				4.83				12.20	130.81	185.47	
18-12-23		1.16	10.17	14.86				14.50	20.94			36.79	89.72	161.90	
18-12-24			11.30	14.86				4.83	6.98			9.20	84.83	116.46	
18-12-29		6.19	14.14	12.71	2.50			9.86				50.30	148.95	278.03	
18-12-30		9.91	27.10	12.71	1.25			3.29				10.86	128.76	190.02	
18-12-36		1.13	17.34	24.74				6.98				29.19	107.60	100.57	
18-12-37		2.26	17.34	11.78	1.27			6.98	6.57			22.16	136.18	127.76	10.63

Appendix A continued.

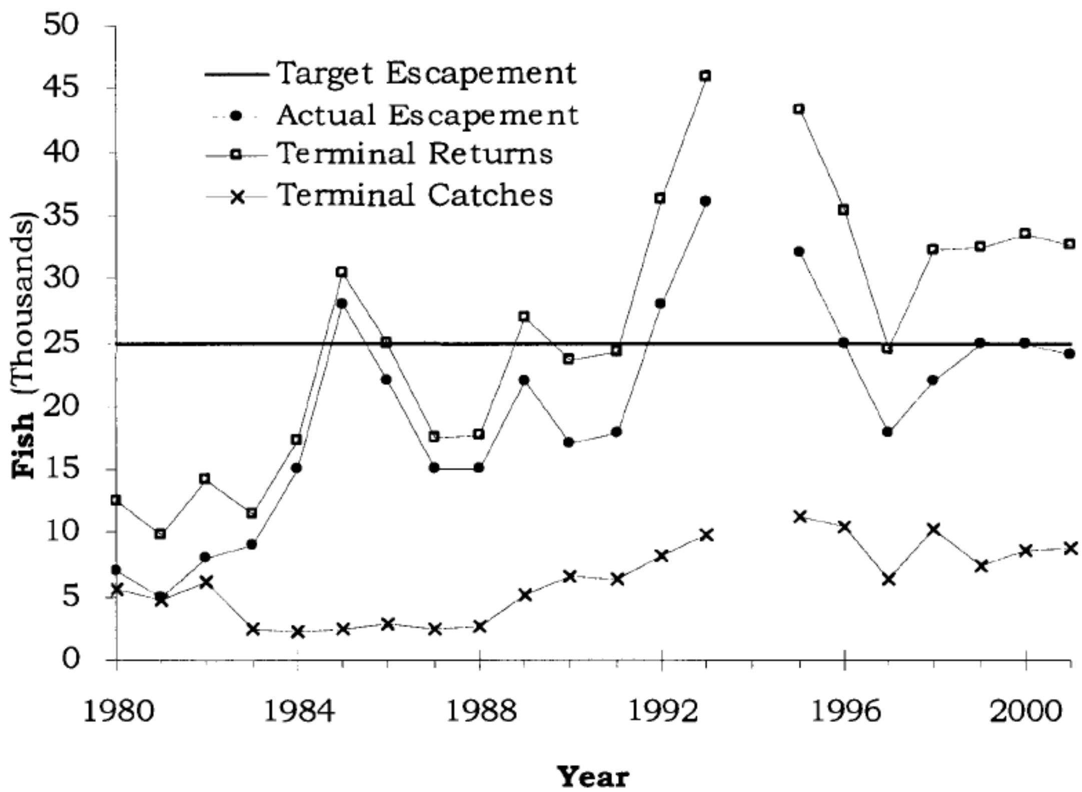
Tagcode	Term N 2	Term N 3	Term N 4	Term N 5	Term N 6	Term S 2	Term S 3	Term S 4	Term S 5	Term S 6	Esc 2	Esc 3	Esc 4	Esc 5	Esc 6
18-12-38			8.67	42.42	1.27			13.96	9.86		27.59	7.03	100.60	468.58	33.88
18-21-52		16.50	8.90	8.76											
18-25-28			2.50	10.09									46.91	45.73	
18-25-29			5.01	4.48					4.54			10.63	35.76	38.26	
18-25-30			3.76	7.85								32.88	30.60	34.79	6.73
18-25-31			3.76	4.48						3.85		12.63	31.60	18.40	1.00
18-25-32			1.25	1.12								10.63	30.60	47.73	
18-25-33		1.27	3.76	1.12			16.32					11.63	59.21	56.66	
18-27-35			3.76	5.60											
18-31-37			4.48	1.26								7.15	10.93	14.47	7.08
18-31-38			1.12	6.32								1.00	5.47	28.94	
18-31-39		1.25	2.24	1.26								7.15	10.93	16.47	
18-31-40			1.12	1.26						2.96			5.47	7.73	
18-31-41			3.36	1.26									5.47		
18-31-42			1.12					4.54					12.93	2.00	
18-31-47		16.50	12.71	28.80	1.12		3.29	40.48				38.92	324.16	225.53	5.47
18-31-48		12.96	19.07	27.55			6.57	32.43				80.84	162.14	263.14	1.00
18-34-10				1.00											
18-38-01		1.12	6.32	2.21								17.40	70.61	26.24	
18-38-02		2.24	5.05	5.53					2.96			7.47	29.20	26.24	
18-38-03		2.24	5.05	5.53	1.00							1.00	20.47	36.39	
18-38-04		4.48	5.05					3.85				60.12	44.41	17.16	
18-38-05		5.60	11.37	7.75			4.54	3.85				17.40	71.35	10.08	
18-38-06		4.48	11.37	3.32			4.54					21.86	56.14	24.24	
18-43-54			2.21	13.00			3.85						23.24	49.14	13.42
18-43-55			3.32	1.00								6.73	31.32	25.07	
18-43-56		1.26	1.11	3.00								6.73	8.08	5.00	13.42
18-43-57			4.43	4.00									10.08	28.07	
18-43-58			4.43	6.00								6.73	15.16	50.14	
18-43-59			5.53									6.73	18.16	1.00	
18-45-48			1.50	4.00			3.85								
18-46-17			3.00	3.29											
18-46-18		1.11	2.00	1.10											
18-46-49			4.38	10.91	1.19								16.42	54.86	
18-46-50			6.57	8.73								11.54	1.00	72.15	16.90
18-46-51			12.05	5.45			4.63					1.00	1.00	101.58	
18-46-52		5.00	6.57	4.36	1.19							3.00	103.94	126.15	
18-46-53		4.00	7.67	6.54					8.04			15.54	46.26	170.87	
18-46-54		1.00	7.67	7.64									58.68	94.58	
18-48-19		2.21	3.00	5.48									14.54	28.84	8.14
18-48-20			1.00	3.29									26.07	16.42	
18-48-21			1.00	2.19									24.07	42.26	8.14
18-48-22		1.11	4.00	3.29								7.08	13.54	13.42	
18-48-23		1.11	6.00	2.19			2.96	4.63					25.07	13.42	
18-48-24			3.00	3.29								7.08	11.54	1.00	8.14
18-49-35			3.27	2.38				8.04	3.26			1.00	36.57	73.59	
18-49-36		1.10	1.09	4.77									57.00	76.59	
18-49-37			4.36	1.19								1.00	54.86	5.00	
18-49-38			4.36	5.96			17.95						43.72	2.00	
18-49-39			2.18	3.58					3.26				33.57	24.90	
18-49-40		1.10	4.36	4.77				16.08	3.26			13.42	50.86	5.00	
18-53-04			10.30	7.06								21.88	56.36	18.52	
18-53-05		4.00	5.72	5.65					5.26				40.24	44.89	
18-53-06		2.00	10.30	7.06								21.88	70.20	30.63	
18-54-25			9.15	11.30								23.88	26.68	43.82	
18-54-27			16.02	8.47								23.88	38.24	29.57	
18-54-28			9.15	11.30				16.16	5.26			21.88	47.80	84.45	
18-62-05			8.47									13.84	27.44		
18-62-06			9.88									9.56	16.39		
18-62-07		1.14	8.47									1.00	41.69		
18-62-08		2.29	2.82									4.28	17.45		
18-62-09												4.28	15.32		
18-62-10		1.14	5.65										3.20		
18-63-62												27.44			
18-63-63												15.32			

* Non-indicator tag codes: 020252 and 026001, released in Nusatsum River, and 180837, 182152, 182735, 184548, 184617, and 184618, released in Salloomt River.

Appendix B. Escapement estimates and methods used to estimate escapement of Chinook salmon in the Atnarko River. Shaded rows indicate years with mark-recapture estimates used to calibrate the three-method average (3M Average) in 1990 to 2010. Escapement 1 refers to the escapement estimate generated by alternative methods. Escapement 2 refers to the escapement estimate generated from the analysis of mark-recapture data. The 3M Average includes methods derived from: (i) average of peak drift counts; (ii) brood stock capture CPUE; and, (iii) number of carcasses pitched.

Year	Escapement 1	Escapement 2	Methods
2010	11,364	11,040	3M Average & Mark-recapture Petersen
2009	11,555	10,780	3M Average & Mark-recapture Petersen
2008	9,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
2007	11,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
2006	26,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
2005	17,500		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
2004	17,600		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
2003	14,890	13,430	3M Average & Mark-recapture Petersen
2002	13,950	16,350	3M Average & Mark-recapture Petersen
2001	24,000	20,770	3M Average & Mark-recapture Petersen
2000	25,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1999	25,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1998	22,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1997	18,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1996	25,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1995	32,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1994	26,800		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1993	35,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1992	27,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1991	17,800		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1990	17,000		Average of peak drift count, brood stock capture CPUE and number of carcasses pitched
1989	22,000		Walk, Float, Other
1988	15,000		Walk, Float, Other
1987	14,425		Walk, Float
1986	21,300		Walk, Float, Heli, Dead Pitch, Tag Recovery, live spaghetti tagging and Carcass Tagging-numbered
1985	27,560		Carcass Tagging-color coded
1984	15,320		Carcass Tagging-not numbered, Stream Bank, Boat, Stream Walk
1983	8,600		Walks, drifts, visual counts
1982	8,000		Walks, drifts, visual counts
1981	4,500		Walks, drifts, visual counts
1980	7,200		Walks, drifts, visual counts
1979	4,500		Walks, drifts, visual counts
1978	15,000		Walks, drifts, visual counts
1977	12,000		Walks, drifts, visual counts
1976	13,000		Walks, drifts, visual counts
1975	4,000		Walks, drifts, visual counts
1974	16,500		Walks, drifts, visual counts
1973	16,000		Walks, drifts, visual counts
1972	18,000		Walks, drifts, visual counts
1971	30,000		Walks, drifts, visual counts
1970	8,250		Walks, drifts, visual counts
1969	12,000		Walks, drifts, visual counts
1968	21,300		Walks, drifts, visual counts
1967	25,000		Walks, drifts, visual counts
1966	14,400		Walks, drifts, visual counts
1965	20,000		Walks, drifts, visual counts
1964	20,000		Walks, drifts, visual counts
1963	20,000		Walks, drifts, visual counts
1962	7,500		Walks, drifts, visual counts
1961	15,000		Walks, drifts, visual counts
1960	7,500		Walks, drifts, visual counts
1959	15,000		Walks, drifts, visual counts
1958	35,000		Walks, drifts, visual counts
1957	15,000		Walks, drifts, visual counts
1956	35,000		Walks, drifts, visual counts
1955	15,000		Walks, drifts, visual counts
1954	15,000		Walks, drifts, visual counts
1953	7,500		Walks, drifts, visual counts
1952	35,000		Walks, drifts, visual counts
1951	15,000		Walks, drifts, visual counts
1950	15,000		Walks, drifts, visual counts

Appendix C. Observed escapement and catch of Atnarko Chinook 1980-2001. Consistent post-season estimates of the total number of spawners (actual escapement), and catches from all three harvester groups (terminal catches) are available since 1980. Actual escapements, rounded to the nearest thousand, can be compared to the management goal of 25,000 spawners (target escapement). Terminal catches include all observed catches from the commercial fishery in the Bella Coola Gillnet Area, the Bella Coola / Atnarko recreational fishery, and the Nuxalk food fishery. Terminal returns are the sum of observed escapement and terminal catches. Figure used with permission from Pestal (2004). 1994 data were not available at the time this figure was created.



Appendix D. Summary of Atnarko Chinook mark-recapture data for years 2001-2003 and 2009-2010.

Year	Sex	No. Tags Applied	No. Tags Recovered	Total No. Carcasses Examined	Modified Petersen	95% lower limit	95% upper limit	Total Petersen Estimate	95% lower limit	95% upper limit	CV
2001	M	751	154	2054	9970	8523	11661	20769	17400	25125	5.6%
	F	562	131	2361	10074	8500	11937				
	J	39	7	144	725	377	1526				
	Total	1352	292	4559	20769	17400	25125				
2002	M	268	36	839	6107	4448	8657	16352	11212	25168	11.7%
	F	229	33	1262	8544	6141	12257				
	J	43	2	115	1701	622	4253				
	Total	540	71	2216	16352	11212	25168				
2003	M	470	63	837	6167	4837	7863	13433	10142	18625	8.5%
	F	399	82	1215	5860	4732	7249				
	J	76	3	72	1405	574	3513				
	Total	945	148	2124	13433	10142	18625				
2009	M	513	90	997	5637	4596	6911	10764	8619	13586	10.2%
	F	289	106	1325	3594	2976	4338				
	J	123	24	308	1533	1047	2336				
	Total	925	220	2630	10764	8619	13586				
2010	M	616	38	344	5458	4004	7422	11037	7611	16045	11.0%
	F	271	43	604	3740	2793	4999				
	J	120	4	75	1839	814	3624				
	Total	1007	85	1023	11037	7611	16045				

Appendix E. Example of the three-method average (3M Average) used to estimate spawning escapement in Atnarko Chinook since 1990. This example shows the computations for the 2005 Atnarko River Chinook escapement estimate (Matt Mortimer, Fisheries and Oceans Canada, Campbell River BC).

1. Population estimate based on CPUE during broodstock collection.

In 1989 it was agreed that the Atnarko Chinook escapement was 22,000 and that the spawners were evenly distributed between the upper and lower Atnarko. Using the 1989 CPUE (13.4/set) for comparison, the 2005 estimate would be:

Upper Atnarko

Sets	50
Catch	1,396
Catch/set	27.92

$$\text{Estimate } \frac{27.92}{13.4} \times \frac{22{,}000}{2} = 22{,}919$$

Lower Atnarko

Sets	40
Catch	1,287
Catch/set	32.18

$$\text{Estimate } \frac{32.18}{13.4} \times \frac{22{,}000}{2} = 26{,}416$$

The peak week of the egg take was used to calculate CPUE therefore the CPUE was slightly higher than the average for the total duration of the spawning period. Also, to reduce egg take costs, broodstock capture has been concentrated in areas with higher densities of fish. In previous years (96-04) a correction factor has been used to account for these changes.

Upper 22,919 x 0.6 = 13,751

Lower 26,416 x 0.6 = 15,850

Adjusted Total 29,601

2. Population estimate based on carcasses handled during deadpitch.

Year	Carcasses Pitched	Pop. Est.
1984	4,003	15,320
1985	4,368	27,560
1986	4,957	21,300
1987		14,425
1988	721	15,000
1989	2,600	22,000
1990	3,759	17,000

1991	3,269	17,800
1992	6,077	27,000
1993	6,381	35,000
1994	5,262	28,000
1995	3,499	32,000
1996	3,758	25,000
1997	1,843	18,000
1998	2,292	22,000
1999	2,378	25,000
2000	3,074	25,000
2001	4,566	24,000
2002	2,271	14,000
2003	2,160	15,000
2004	1,935	17,500

Total population estimate 1984-1986, 1988-2004	=	443,480
Total carcasses handled 1984-1986, 1988-2004	=	69,173
Spawning estimate per carcass pitched	=	6.41
Carcasses pitched in 2005 (see below)	=	1,682**
2005 population estimate	=	10,784

**For 2005, a high water event in late September occurred right around the peak of the dead-pitch. This is the second time that this has happened in the last 20 years (John Willis, Snootli Creek Hatchery, pers. comm.). Unfortunately, after the high water levels, the number of carcasses dropped off dramatically and the final number of carcasses pitched (1,453) was not representative of the run.

To determine an expansion factor for the 2005 number of carcasses pitched, the dead-pitch data from 2001 to 2003 was examined. The 2004 dead-pitch data was not included, as the methodology for that year included expanding the results after examining only three of the six reaches (1, 4, and 5).

Using September 18 as the normal start date of the dead-pitch, 58% of the inspections (effort) were completed and 1,150 carcasses were examined, as of September 27, 2005. For the 2001 to 2003 dead-pitch data, the number of carcasses was expressed as a percentage of the total number of carcasses at a point that corresponded to 58% of the effort for that particular year. The three percentages were then used to obtain the total number of carcasses in 2005, by applying them as expansions to the 1,150 carcasses pitched before the high water event in 2005. The three estimates were then averaged to determine the number of carcasses pitched in 2005. This estimate is believed to be a conservative representation of the number of carcasses examined in 2005.

3. Population Estimate based on drifts

August 24/25 – Total estimate	9,643
September 7/8 – Total estimate	7,376

September 13/14 – Total estimate 12,066

The inspections on August 24/25 and September 7/8 were during low, clear water conditions. The late August inspection was well before the spawn, while the early September inspection was just as the fish were starting to spawn. By the mid-September inspection, the spawn was well underway, however observations were difficult. Water and light conditions were fair to moderate, and the above estimate should be viewed as slightly conservative, as many of the deeper pools couldn't be enumerated efficiently. Using a peak count, as has been done in the past, our estimate for this method would be 12,066.

The final estimate for the escapement of Atnarko Chinook will be a rounded average based on the 3 methods listed below:

Population estimate based on CPUE during brood stock collection	- 29,601
Population estimate based on carcasses handled during deadpitch.	- 10,784
Population estimate based on drifts	- 12,066
Average	- 17,484

The estimate for the Atnarko Chinook escapement for 2005 is 17,500 spawners.

Appendix F. Simple representation of calculations used in cohort analysis with CWT data in COSHAK4 and COHSHK11e.

The following calculations are used in the cohort analysis with coded-wire tag data.
Each relates to a particular age from a particular brood from a particular stock.
Most of the equations used in the cohort analysis program are structured such that values for the oldest age are calculated first working 'backward' to the youngest age.
They require this structure to calculate desired quantities correctly.

# Ocean Cohort size at age:
OceanCohort[a]=(OceanCatch[a]+TotTermRun[a]+OceanCohort[a+1])/(1-NatMort[a])

# Ocean Exploitation Rate at age:
OceanER[a]=OceanCatch[a]/(OceanCatch[a]+TotTermRun[a]+OceanCohort[a+1])

Note that the denominator is also equivalent to the OceanCohort[a] (i.e., the cohort size after natural mortality has occurred)

# Maturation Rate:
MR[a]=TotTermRun[a]/(TotTermRun[a]+OceanCohort[a+1]) or,
MR[a]=TotTermRun[a]/OceanPostFisheryAbundance[a]

'OceanPostFisheryAbundance' = total terminal run (mature pop) + survivors of ocean fisheries that are not maturing

The denominator in the above equation could also be:
Prefishery ocean abundance (Cohort[a]*SurvRate[a]) at age minus total ocean catch at age

# Alternatively:
MR[a]=TotTermRun[a]/((Cohort[a]*SurvRte[a])-TotOcnCat[a])

# Adult Equivalent Rate:
AEQ[a]=MR[a]+((1-MR[a])*(1-NatMort[a+1])*AEQ[a+1])

Both the MR and AEQ equations assumes a value equal to 1 for the maximum (i.e. designated oldest) age for a particular stock. These values are calculated starting with the age that is one less than the maximum age.

# Cohort Survival Rate at age:
CohortSurvivalRate[a]=(OceanCohort[a]/TotalRelease[BY])*100

Calculations to obtain the cohort size at age for incomplete broods:

The CTC's cohort analysis programs use the following approach to obtain the cohort sizes for each age present in a brood. For the oldest age present in a brood (but less than the designated max age), the cohort size (before natural mortality) is calculated using the long term average mat rate for the age from all completed broods. Use the following formula is:

Cohort[a]=((TMR[a]/LTA_MR[a])+OceanCatch[a])/NatMort[a]
*Note: this is the cohort size that appears in the *cby.out files; the cohort size in the .hrj files is the cohort size after natural mortality at age, where:

TMR = total mature run (esc + fresh water catch + net catch in ocean of mature)
LTA_MR = long term average of the maturation rate for all complete broods for the age
OceanCatch = essentially all catch not considered terminal or mature for an age

Conversely,
MR[a]=TMR[a]/((Cohort[a]*NatMort[a])-OceanCatch[a])

For younger ages in an incomplete brood, the cohort size at age is calculated by:
Cohort[a]=(TMR[a]+OceanCatch[a]+Cohort[a+1])/NatMort[a]

The cohort size is then used to calculate the preterminal ERs, the MR and the cohort survival rate. The MR output to the *.out files for each age in incomplete broods is the long-term average NOT the maturation rate that actually fits the data. Thus, while the MR at age for complete broods and for the oldest age in incomplete broods can be used to recreate the cohort size, as in:

Cohort[a]=((TMR[a]/MR[a])+OceanCatch[a])/NatMort[a]

The above does work for ages younger than the oldest one in incomplete cohorts.

Preterminal ER[a]=Catch[f,a]/(Cohort[a]*(1-NatMort[a]))

Note that the Cohort[a+1] represents the fish that didn't die of natural causes, didn't get caught in the ocean and didn't mature. They are the immature survivors that pass on to the next age and thus, are the starting cohort for the next age before natural mortality occurs.

Appendix G. Simple representation of options and their calculations in cohort analysis with CWT data in COSHAK4 in cases with no escapement or poor escapement data.

1.1. Escapement Options

1.1.1. Option 1 (enter maturation rates)

The computations for this option occur within the subroutine ComputeNewEsc (see code below).

This option divides the total preterminal and terminal catch for the maximum age, TempTotCat(MAge), by the harvest rate for the maximum age, TempMR(Mage), to obtain an estimate of the cohort size after natural mortality for the maximum age. Then it subtracts the total preterminal and terminal catch for the maximum age, TempTotCat(MAge), from the maximum age cohort size after natural mortality to obtain an estimate of escapement for the maximum age, NewEsc(Mage). This assumes that there are no fish alive that are older than your maximum age and that all fish caught for that age were mature.

The cohort size before natural mortality for the maximum age, cohort(Mage), is calculated by adding the total preterminal and terminal catch, TempTotCat(Mage), and the estimated escapement, NewEsc(MAge), and dividing by the survival rate, (1 - Form1_newWeight.NATMORTRTE (MAge)).

The terminal run, termrun, for the next youngest age is estimated by calculating the cohort size before maturation and then subtracting the maximum age cohort size before natural mortality. The terminal run for all other ages is calculated in a similar fashion by calculating the cohort size before maturation and then subtracting the cohort size before natural mortality from the next highest age. The new escapement values, NewEsc(j), are then calculated by subtracting the terminal catch, TempTR(j), from the terminal run, termrun.

```
Sub ComputeNewEsc()

Dim cohort(MAge) As Single

Dim termrun As Single

If TempMR(MAge) > 0 Then

NewEsc(MAge) = (TempTotCat(MAge) / TempMR(MAge)) - TempTotCat(MAge)

End If

cohort(MAge) = TempTotCat(MAge) + NewEsc(MAge) / (1 -
Form1_newWeight.NATMORTRTE(MAge))
```

```
For j As Integer = MAge - 1 To Form1_newWeight.startAge Step -1

termrun = cohort(j + 1) / (1 - TempMR(j)) - cohort(j + 1)

If termrun > TempTR(j) Then

NewEsc(j) = termrun - TempTR(j)

End If

cohort(j) = (cohort(j + 1) + TempTotCat(j) + NewEsc(j)) / (1 -
Form1_newWeight.NATMORTRTE(j))

Next

End Sub
```

1.1.2. Option 2 (enter escapements directly)

This option allows the user to enter the escapement numbers manually.

1.1.3. Option 3 (enter exploitation rates)

This option allows the user to enter externally estimated exploitation rates for each age and it is executed in the ShowEscData3 form. The new escapement values are calculated for each age by dividing the total catch for an age (totcat(age)) by the exploitation rate for that age (ER(age)) and then subtracting the total catch for that age (totcat(age)) using the following equation:

NewEsc(age) = (totcat(age) / ER(age)) - totcat(age)

1.1.4. Option 4 (out-of-base procedure)

In a simplified description, the terminal harvest rate by fishery I and age J is calculated from the c-file data using the following equation:

HRCat(I, J) = MyCATCH(I, J) / termrun
HRCat(I, J) = terminal harvest rate in fishery I for age J
MyCATCH(I, J) = catch in fishery I and age J from the cfile
termrun = terminal run for a particular age, equivalent to the terminal catch + Escapement from cfiles

Then, the terminal harvest rate calculated above is adjusted using the following equation:
HRCat(Fish, J) = HRCat(Fish, J) / AdjustWeight(Fish, yr)
HRCat(Fish, J) = terminal harvest rate in fishery Fish for age J
AdjustWeight(Fish, yr) = fishery index scalar from the .WG4 file

The terminal catch is calculated using the adjusted harvest rate as:
TempCatch(Fish, age) = TermRun * HRCat(Fish, age)
TempCatch(Fish, age)= terminal catch for fishery Fish and age J

Finally, the escapement is calculated as:
Escape(age) = TermRun – MATCATCH
MATCATCH = sum of TempCatch(Fish, age) for a particular age

Appendix H. Example of a C-file for Atnarko Summer Chinook (ATN) representing CWT recoveries by age from tag code 025958.

025958	Tag code
88	Brood year
26470	Number tagged
49118	Number released
6	Maximum age
61	Number of fisheries

Fishery names

AK WIN1 S/O T
AK WIN1 N/O T
AK WIN1 S/I T
AK WIN1 N/I T
AK WIN2 S/O T
AK WIN2 N/O T
AK WIN2 S/I T
AK WIN2 N/I T
AK SPR S/O T
AK SPR N/O T
AK SPR S/I T
AK SPR N/I T
AK JUNE S/O T
AK JUNE N/O T
AK JUNE S/I T
AK JUNE N/I T
AK JULY S/O T
AK JULY N/O T
AK JULY S/I T
AK JULY N/I T
AK FALL S/O T
AK FALL N/O T
AK FALL S/I T
AK FALL N/I T
SWVI FALL T
SWVI WIN T
SWVI SPR T
SWVI SUM T
NWVI FALL T
NWVI WIN T
NWVI SPR T
NWVI SUM T
GEO ST T
N/CNTR T
NBC FALL T
NBC WIN T
NBC SPR T
NBC SUM T
WASH T
OREG T
ALSK N
WASH CST N
JU DE F N
SWVI N
GEO ST N
CENTR N
NORTH N
JOHN ST N
FRASER N
PG SD 7 N
PG SD 7A N
PG SD OT N
TERMIN N
ALSK S
SWVI S
GEO ST S
CENT&NTH S
WASH OCN S
PG SD N S
PG SD OT S
TERMIN S

Recoveries by age and fishery. Rows are ages (row 1 is age 2, row 2 is age 3, row 3 is age 4, row 4 is age 5, and row 5 is age 6). Columns are fisheries (4 columns per fishery; last 4 columns are escapement)

```
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000004000000000000000000000000000000000000000000000000000000000000000007
0000000000000000000000030000000000000000000000000000000300000000000300000000000100000000000000000000000000000000000000000000000000000007000000000000000600000000000000000000000000140000000000000000000000000003000000000000000000000000000000000029
0000000300000000000000200000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000500000004000000000000000000000000000000000000000000160000000000000000000000000003000000000000000400000000000000000066
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
```

Appendix I. MDL file for Atnarko Summer Chinook (ATN) representing base period CWT recoveries by age, as derived from the escapement procedure in COSHAK4. CWT tag codes from brood years 1976-78 were used.

ATN	Stock
MODEL	
203315	Number tagged
211685	Number released
6	Maximum age
32	Number of fisheries
AKW/S T AKJNI T AKJNO T AKJLI T AKJLO T AKFALL T NORTH T CENTRL T WCVI F/W T WCVI SPR T WCVI SUM T WASH/OR T GEO ST T ALASKA N NORTH N TCENTRL N WCVI N J DE F N PGSDN N PGSDO N WASH CST N TERMN N JNST N FRASER N ALASKA S NTH/CENT S WCVI S WASH CST S PGSDN S PGSDO S GEO ST S TERMN S	Fishery names
000000000000000000000000000000000000000000000000000000000000110000400000000180000000000000000000000000000000020000000000000000000000000000000000000000150000000004 0000000000000030001100009000000000090000400000000000000000000000000000016000040004200000000100000000000000000000000002000000000400008000000000000000000000000130000000099 000070000000006200008000100001000028000150000000008000000000000000000000001100101000000000000000000000000000000000000000001000000000000000000000000000000000001200409 000440001500084000030004500000000107000680000000000000000000000000000000006000000005700014000000000000000000000000000000000000000060002500000000000000000000000000000300703	Recoveries by age and fishery *

* Rows are ages (row 1 is age 2, row 2 is age 3, row 3 is age 4, and row 4 is age 5 and 6 pooled); Columns are fisheries (4 columns per fishery); Last 4 columns are escapement

Appendix J. MDL file for Atnarko Summer Chinook (ATN) representing base period CWT recoveries by age, as derived from the out-of-base procedure in COSHAK4. CWT tag codes from brood years 1987-90 were used. Note the number of fisheries is collapsed from 61 (in the C-files) to 32 in the MDL file.

```
ATN
MODEL
598358
8181566
6
32
AKW/S T
AKJNI T
AKJNO T
AKJLI T
AKJLO T
AKFALL T
NORTH T
CENTRL T
WCVI F/W T
WCVI SPR T
WCVI SUM T
WASH/OR T
GEO ST T
ALASKA N
NORTH N
TCENTRL N
WCVI N
J DE F N
PGSDN N
PGSDO N
WASH CST N
TERMN N
JNST N
FRASER N
ALASKA S
NTH/CENT S
WCVI S
WASH CST S
PGSDN S
PGSDO S
GEO ST S
TERMN S
000000000000000000000000000000000000000000000000000000000000000000000100000000000000000000000000000000000000010000000000000000000000000000000000000000000000000000600001
000000000000000000000000000000000210000000000000000000000000000000000000060000000307000000000000000000000000000000000008000000000000000300002000000000000000000000000000700081
000470005200055000240004400024001650035100000000000000080000000000000000000000800770000000000000000000000000000000000060000000000000000200021000000000000000000000000000003000703
003790001900000000750003000004000500013300000000000000030000000000000000000000801540000000000000000000000000000000000146000000000000000100006200000000000000000000000000005701533
```