Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

C S A S | **S C C S**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2004/129

Document de recherche 2004/129

Not to be cited without
~~Permission of the authors~~

Ne pas citer sans
~~autorisation des auteurs~~

Habitat-based production goals for coho salmon in Fisheries and Oceans Statistical Area 3

Objectifs de production axés sur l'habitat pour le saumon coho dans le secteur statistique 3 de Pêches et Océans Canada

R.C. Bocking[1] and D. Peacock[2]

[1]LGL Limited Environmental Research Associates
9768 Second Street
Sidney, B.C. V8L 3Y8

[2]Fisheries and Oceans Canada
417- 2nd Avenue West
Prince Rupert, B.C. V8J 1G8

ISSN 1499-3848 (Printed / Imprimé)

Canada

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ACKNOWLEDGMENTS

We would like to acknowledge the contribution of several people to the development of this model. Peter Wainwright, Robin Tamasi, Lucia Ferreira, Karen Truman, and Tony Mochizuki of LGL all participated in the development of the GIS components of the model to calculate accessibility from TRIM data. Mansell and Kimi Griffin of the Nisga'a Lisims Government also assisted with the GIS calculations for the Coastal Nass Area streams. Bill Gazey conducted statistical analyses for predicted smolt output. The support for this project by Nisga'a Lisims Government, particularly Harry Nyce, is greatly appreciated. We also thank Michael Bradford for providing the region wide dataset of smolt yields and for reviewing the manuscript. Thanks also to Chuck Parken for reviewing the manuscript and to Joel Sawada for reviewing the manuscript and assisting with the gathering of data for Lachmach, Toboggan and Alaskan coho streams.

ABSTRACT

Smolt productive capacity and the number of spawners that are required in order to fully seed the available habitat and produce the maximum number coho smolts (S_{max}) were estimated for 102 coho streams in Statistical Area 3 using a habitat-based model. Stream length accessible to coho salmon was determined from terrain resource inventory maps (TRIM) using GIS. Stream order, gradient and known barriers were used to define the accessible length of stream. The number of smolts per kilometre was derived using two models. The first used a log-linear predictive regression of smolt yield and stream length for Alaskan and British Columbia streams. The second used recent decadal smolt yield and stream length for three northern British Columbia coho indicator streams (Lachmach, Zolzap, and Toboggan). Estimates of smolt productive capacity and required spawner numbers were stratified into four geographic regions of Statistical Area 3; Outer Coastal Area, Outer Nass Area, Lower Nass Area, and Nass River Area. The predicted smolt yield from both models for Zolzap Creek was comparable to maximum smolt yield from Ricker and Hockey Stock smolt recruitment relations. However, the estimated required number of spawners to seed the available habitat in Zolzap Creek, and for all streams in general was highly variable and depended on the assumed values of egg-to-smolt survival and the number of smolts produced per spawner.

RÉSUMÉ

La capacité de production des smolts et le nombre de géniteurs nécessaires pour ensemencer complètement l'habitat disponible et pour produire un maximum de smolts de coho (S_{max}) ont été estimés au moyen d'un modèle fondé sur l'habitat pour 102 cours d'eau à saumon coho dans le secteur statistique 3. La longueur des cours d'eau accessible au saumon coho a été déterminée à partir de cartes d'inventaire des ressources sur le terrain (terrain resource inventory maps (TRIM)) dressées à l'aide d'un SIG. L'ordre, la pente et les obstacles connus des cours d'eau ont été utilisés pour établir la longueur accessible au saumon. Le nombre de smolts par kilomètre a été obtenu à l'aide de deux modèles : le premier était une régression prévisionnelle log-linéaire du nombre de smolts produits dans les cours d'eau de l'Alaska et de la Colombie-Britannique et de la longueur de ces cours d'eau; le deuxième à utilisé des données décennales récentes sur la production de smolts dans trois cours d'eau indicateurs à saumon coho du nord de la C.-B. (Lachmach, Zolzap et Toboggan) et sur la longueur de ces cours d'eau. Les estimations de la capacité de production des smolts et du nombre de géniteurs nécessaires ont été classées selon quatre régions géographiques du secteur statistique 3 : zone côtière extérieure, zone extérieure de la rivière Nass, la zone du cours inférieur de la rivière Nass et la zone de la rivière Nass. Les prévisions de la production de smolts dans le ruisseau Zolzap obtenues à l'aide des deux modèles étaient comparables à la production maximale de smolts obtenue à l'aide des modèles de recrutement de Ricker et de type « bâton de hockey ». Cependant, l'estimation du nombre de géniteurs requis pour ensemencer l'habitat disponible dans le ruisseau Zolzap, et dans l'ensemble des cours d'eau en général, était très variable et dépendait des valeurs présumées du taux de survie de l'œuf au smolt et du nombre de smolts produits par géniteur.

INTRODUCTION

The need to establish escapement goals based on stock-specific productive capacity is fundamental to wild stock conservation and sustainability of coho salmon (*Oncorhyncus kisutch*) fisheries in British Columbia. Canada's draft Wild Salmon Policy states that target and limit reference points will be determined for each salmon conservation unit based on estimates of productive capacity (Fisheries and Oceans Canada 1998). Other jurisdictions that have recently developed new policies regarding biological escapement goals or reference points include Oregon, Washington and Alaska.

In Alaska, the state constitution mandates the Alaska Department of Fish and Game (ADF&G) to manage fishery resources on the sustained yield principle (ADF&G 2001), requiring establishment of escapement goals. Escapement goals or reference points are to be defined on the basis of maximum sustained yield (MSY) with uncertainties explicitly stated.

In Washington State, the Department of Fish and Wildlife developed the Joint Wild Salmon Policy (WDFW 1997). The WDFW spawning escapement policy states "escapement rates, levels or ranges shall be designated to achieve MSY and will account for all relevant factors including current abundance and survival rates, habitat capacity and quality, environmental variation, management precision, and uncertainty and ecosystem interactions." Still others have recommended that escapement goals need to explicitly account for freshwater productivity requirements such as nutrients from spawning carcasses (Cederholm et al. 2000). In Oregon, estimates of carrying capacity are needed by fishery managers to implement the Oregon Wild Fish Management Policy (ODFW 1992).

Each of these policies infer the need to develop salmon escapement goals or reference points based on some measure of the ability of the stream (and marine) ecosystem to produce salmon. However, estimating the productive capacity using conventional stock assessment techniques (e.g., stock recruitment analysis) for each of the numerous coho stocks within a given management area is a costly endeavour and greatly beyond the fiscal capability of Fisheries and Oceans Canada. As well, the inherent difficulties in obtaining direct estimates of juvenile coho production, catch estimates and spawner abundance on a stock-specific basis preclude the use of a stock recruit approach to estimate productive capacity for coho salmon. Hence, for virtually all coho streams in British Columbia, there remains uncertainty regarding the appropriate escapement goals for coho salmon. Moreover, stock recruitment analysis, a proposed method to calculate the required number of spawners for coho in Statistical Area 3, would produce unreliable estimates as a result of the high variability typically associated with spawner-recruit data.

The establishment of regional or area-specific aggregate escapement goals for coho salmon is a more realistic goal and is also in keeping with the management methods currently used for the many mixed-stock coho fisheries in British Columbia. For example, Nisga'a entitlements to Nass Area coho are based on a fixed percentage (8%) of the total return to Canada (TRC) for the Nass Area aggregate, not specific stocks. Another example is Fraser River coho which are managed to a single exploitation rate across all major stocks (Fisheries and Oceans Canada 2003). As stock identification techniques for coho improve and are implemented inseason, harvest rates may be targeted towards smaller stock groupings than currently possible.

An alternative to spawner-recruit relationships for determining productive capacity for coho is habitat capacity modelling. Numerous authors have investigated relationships between fish abundance in streams (number of spawners, smolt yield, fry density, etc.) and physical habitat variables (e.g., Baranski 1989, Reeves et al. 1989, Holtby et al. 1990, Marshall and Britton 1990, Jowett 1992, Nickelson et al. 1992, Bradford et al. 1997, Rosenfeld et al. 2000, Pess et al. 2002). Faush et al. (1988) reviewed 99 models that predict the abundance of stream fish from habitat variables. Water temperature, flow, depth, velocity, water quality, food availability, channel characteristics, and watershed characteristics have all been considered in models (Jowett 1992). These multi-variate models require intensive amounts of data for specific habitat characteristics and may or may not be suitable beyond specific species, streams or geographic regions. For the majority of the nearly 2,600 spawning populations of coho salmon in British Columbia (Slaney et al. 1996), these data simply do not exist and would be too costly to collect.

One approach suggested by several authors (Holtby et al. 1990, Marshall and Britton 1990, Bradford et al. 1997, Nickelson 1998, and Bocking et al. 2001) has been to quantify the amount of freshwater rearing habitat that limits freshwater production within a stream or watershed and then predict fry or smolt yield from the habitat parameter. This approach assumes that the average number of coho juveniles produced from a stream is an appropriate measure of a stream's "average" production potential or capacity (Marshall and Britton 1990, Bradford et al. 1997). Burns (1971) defined stream carrying capacity as: "the greatest weight of fishes that a stream can naturally support during the period of least available habitat. It should be considered a mean value around which populations fluctuate." Carrying capacity in terms of juvenile salmon production can only be achieved when a stream is adequately seeded with spawners.

The general belief is that the majority of coho production is derived from smolts (stream type) of varying freshwater age (1-3 years in freshwater) (Mason 1975, Crone and Bond 1976). It is also believed, however, that coho fry (ocean type) that leave their natal stream can also contribute, in part, to total production by successfully rearing in neighbouring streams or estuarine environments (Tschaplinksi 1987, Irvine and Johnston 1992). The contribution of this life-history strategy is also inferred from discrepancies in the proportion of smolts coded-wire tagged at exodus from the natal stream and the proportion of returning adults coded-wire tagged (e.g. Baxter 2003, black, French, coldwater, etc.).

While numerous studies have documented the downstream movement and presumed emigration of coho fry from the freshwater environment, few have quantified the contribution of this life-history component of the population to total adult return. Bradford et al. 2000 suggested that fry migrants could contribute significantly to total production if there are significant amounts of suitable habitat in non natal areas where they are able to rear to smolt stage before entering the marine environment. However, until quantitative studies are conducted to document the contribution of fry to total adult return, it is appropriate to assume that the majority of coho production in terms of adult returns is derived from stream type coho.

Physical Habitats Limiting Coho Production

Freshwater habitat quantity and quality determines the number of coho salmon smolts that a stream can produce, typically referred to as carrying capacity of the stream. The limiting habitat of a stream is that which is required to support a particular life stage but is in shortest supply. For coho salmon, five freshwater life stages are typically recognized: 1) spawning and incubation; 2) spring fry; 3) summer parr; 4) winter pre-smolts; and 5) smolts. Most coho populations smolt after one year in freshwater, but some portion of some populations can spend up to two or three years before smolting.

When the habitat needed during a particular life stage is in short supply, a bottleneck is created and the population suffers density-dependent mortality (Reeves et al. 1989). The most common limiting seasons for coho salmon are late summer or winter and correspond to sustained periods of low flows. Low stream flows can reduce available habitat to coho primarily by:

1. Narrowing the stream channel;
2. Reducing the number of pools and off channel areas;
3. Reducing the size and depth of pools and off channel areas; and
4. Reducing nutrient inputs to the stream by isolating watered areas from riparian vegetation.

This reduction in habitat available can occur during late summer at which time the recruitment of winter pre-smolts would be limited, or during winter at which time the recruitment to smolts would be limited.

Solazzi et al. (2000) found that improving overwintering habitat for coho salmon parr and smolts in Oregon streams resulted in a significant gain in productivity. These overwintering areas tend to be in the lower reaches of streams where deep water pool habitat with cover and off channel habitat is typically more abundant.

Predicting Smolt Abundance from Physical Habitat

Studies have shown that carrying capacity of a stream is related to physical attributes of the stream (Marshall and Britton 1990). For example, Burns (1971) found that stream surface area provided the best correlation with absolute biomass (all species) for seven northern California streams. Chapman (1965) found similarity in coho densities among Oregon streams on a per unit area basis. Mason and Chapman (1965) found coho production in Oregon to be most strongly correlated with stream area. Lister (1968) found little difference in coho smolt yield per unit of stream length in five British Columbia streams and concluded that 2,484 smolts per kilometre was a useful biostandard for determining yield. Interestingly, Mason (1974) found that coho fry biomass could be increased substantially by augmenting the food supply with daily feedings of euphausiids. However, smolt yield did not increase beyond expected natural levels.

Bradford et al. (1997) examined the relationship between mean smolt abundance and physical habitat features from a database of 474 annual estimates of smolt abundance from 86 streams in western North America. They found that only stream length and to a lesser extent latitude was useful in predicting mean smolt abundance. Mean coho salmon smolt abundance was strongly correlated with stream length ($R^2 = 0.70$, Bradford et al. 1997). Marshall and Britton (1990) found that both stream length and useable area were good predictors of mean smolt abundance for 24 streams in the Pacific Northwest. Holtby et al. (1990) and Nickelson (1998) obtained similar results with their datasets. Rosenfield et al. (2000) also found no decline in coho abundance per linear kilometre of stream for 119 observations in British Columbia, which is consistent with the observations of Bradford et al. (1997) that coho smolt production is a simple linear function of stream length.

The approach of Bradford et al. (1997) assumes that the representative datasets in the model contain sufficient years of data to approximate mean smolt abundance, at least for the period covered by the data set. They may or may not represent periods of high smolt production, low smolt production, or average smolt production. Nevertheless, they are the best estimates available for smolt production from the various streams.

Using known or literature values of survival, coho smolt production estimates can then be used to derive estimates of the required spawners to fully seed the available habitat and yield maximum smolt production or capacity. It is this number of spawners required to maximize smolt capacity production (S_{max}) that the models developed in this paper are attempting to predict. Note that the model does not account for potential production arising from ocean-type coho that might emigrate from freshwater systems in their first year of life, rear in non-natal areas and still contribute to resulting adult returns.

Study Area

The study area for this work includes all of Fisheries and Oceans Statistical Area 3. The southern boundary of Statistical Area 3 stretches from Dundas Island across Green Island to Port

Simpson (Figure 1). Area 3 includes all Canadian waters north of this boundary, including Observatory Inlet, Portland Inlet, Pearce Canal, and the Nass River.

Statistical Area 3 encompasses two ecoprovinces (Coastal Mountains and Sub-Boreal Interior) and contains six biogeoclimatic zones: Alpine Tundra, Sub-Boreal Spruce, Engelmann Spruce-Subalpine Fir, Interior Cedar-Hemlock, Mountain Hemlock, and Coastal Western Hemlock (Meidinger and Pojar 1991).

There are a total of 102 known coho streams within Area 3 (Appendix A). Forty-four of these are in coastal areas and fifty-eight are within the Nass River drainage. Coho escapements vary significantly among all streams. Escapement data for the region are generally poor with not all coho-bearing streams represented in the Fisheries and Oceans database and only two systems having what could be considered rigorous counts (Meziadin River and Zolzap Creek; Table 1). Additional estimates have been obtained for several streams using Area-Under-The-Curve methods since 2000.

Current Management of Area 3 Coho

Area 3 coho are harvested in mixed-stock commercial, recreation, and First Nation fisheries. Fisheries and Oceans Canada manages these fisheries to a maximum 15% Canadian exploitation on aggregate North and Central coast coho stocks. Alaskan fisheries have typically harvested between 20% and 40% of Area 3 coho stocks for a combined US and Canada harvest rate of between 35% and 55%. As well, the Joint Fisheries Management Committee (JFMC)[1] for the Nisga'a Final Agreement is tasked with ensuring that Nisga'a entitlements as mandated by the Final Agreement are achieved.

To deliver Nisga'a entitlements as per the Nisga'a Final Agreement and to optimize fishing benefits for all Canadians has required that methods be developed to estimate the total harvest and escapement of Area 3 coho as well as the establishment of escapement reference points. In 2000, indicator stocks were established to provide annual escapement estimates in the Coastal

[1]The Joint Fisheries Management Committee is a tripartite committee consisting of representatives of Nisga'a Lisims Government, the government of Canada, and the government of British Columbia.

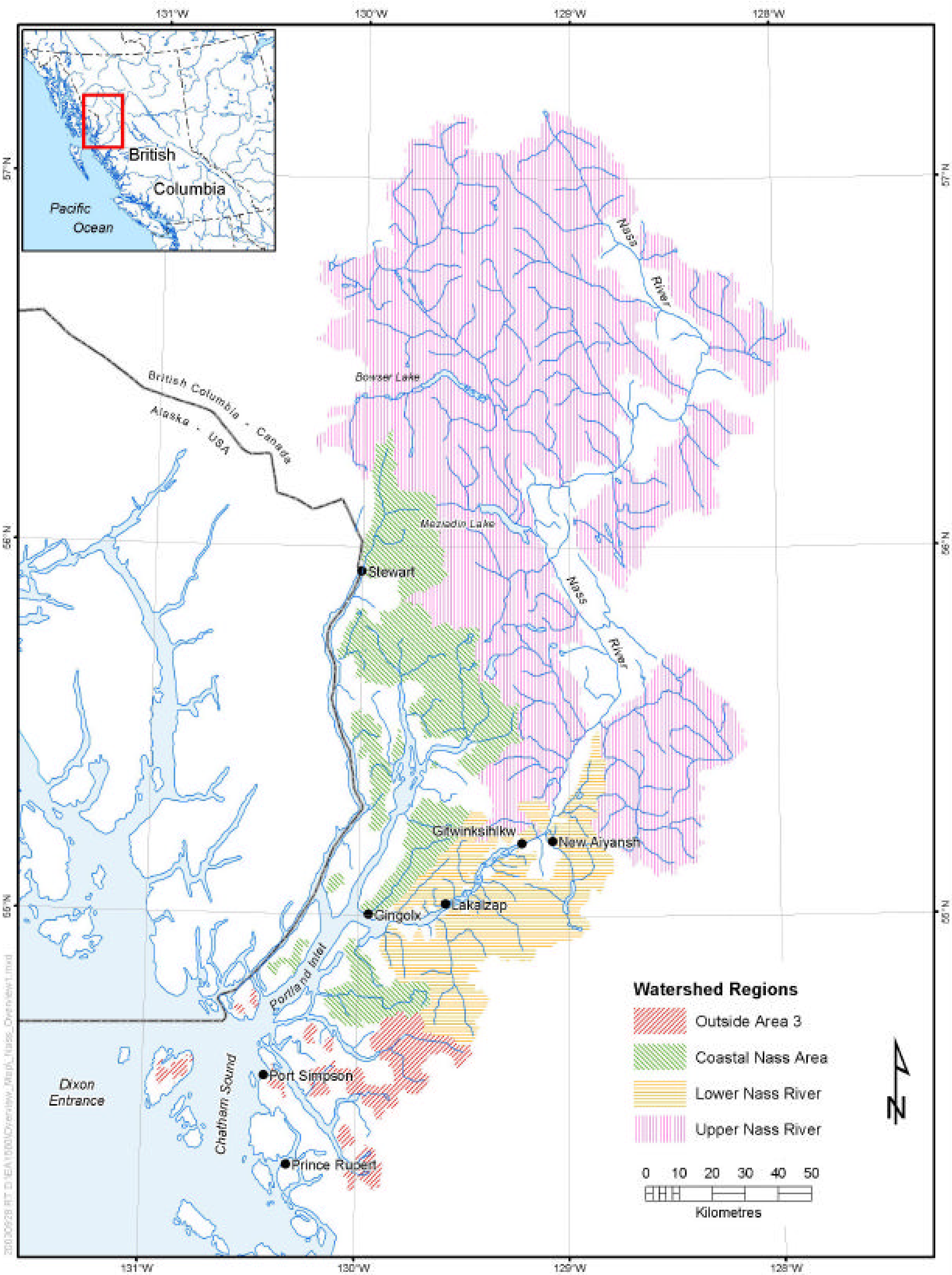

Figure 1. Map of Statistical Area 3 and coho streams.

Table 1. Area 3 average coho escapement, 1950 to 1999 (DFO, Prince Rupert).

SUBAREA	STREAM NAME	Mean 1950-59	1960-69	1970-79	1980-89	1990-99	Maximum Recorded
PORTLAND CANAL	BEAR RIVER	975	3,333	2,219	2,071	625	7500
PORTLAND CANAL	BELLE BAY CREEK	-	-	-	11	-	100
PORTLAND CANAL	DOGFISH BAY CREEK	30	-	69	63	52	500
PORTLAND CANAL	DONAHUE CREEK	-	-	-	-	-	-
PORTLAND CANAL	GEORGIE RIVER	-	3,475	817	-	-	12000
PORTLAND CANAL	RAINNY CREEK	-	-	83	350	88	500
PORTLAND CANAL	ROBERSON CREEK	-	82	63	-	-	400
OBSERVATORY INLET	CASCADE CREEK	-	-	-	-	-	-
OBSERVATORY INLET	ILLIANCE RIVER	1,422	150	165	550	375	3500
OBSERVATORY INLET	KITSAULT RIVER*	516	1,080	1,270	1,157	-	3000
OBSERVATORY INLET	KSHWAN RIVER	513	-	-	544	-	2000
OBSERVATORY INLET	OLH CREEK	-	-	-	25	-	100
OBSERVATORY INLET	SALMON COVE CREEK	-	-	-	21	-	100
OBSERVATORY INLET	STAGOO CREEK	-	-	89	171	-	600
OBSERVATORY INLET	WILAUKS CREEK	-	-	-	406	-	3000
NASS RIVER	ANLIYEN CREEK	-	-	220	363	-	700
NASS RIVER	ANSEDAGAN CREEK	-	153	141	214	30	750
NASS RIVER	BOWSER RIVER & LAKE	-	-	-	-	-	-
NASS RIVER	BROWN BEAR CREEK	-	-	45	129	-	350
NASS RIVER	CHAMBERS CREEK	-	-	-	113	107	320
NASS RIVER	CRANBERRY RIVER	-	1,200	3,167	2,213	333	6000
NASS RIVER	DAMDOCHAX RIVER & LAKE	-	-	170	638	-	1000
NASS RIVER	DISKANGIEG CREEK	-	75	586	600	-	1800
NASS RIVER	GINGIT CREEK	-	344	307	78	50	750
NASS RIVER	GINLULAK CREEK	-	1,050	795	855	467	3500
NASS RIVER	GITZYON CREEK	44	239	81	30	0	750
NASS RIVER	IKNOUK RIVER	-	-	-	1,419	500	5000
NASS RIVER	ISHKHEENICKH RIVER	550	5,125	2,175	1,838	-	7500
NASS RIVER	KINCOLITH RIVER	381	-	300	1,780	1,500	5000
NASS RIVER	KINSKUTCH RIVER	-	-	17	27	-	50
NASS RIVER	KITEEN RIVER	-	965	779	192	-	3500
NASS RIVER	KSEDIN CREEK	-	159	92	68	90	400
NASS RIVER	KWINAGEESE RIVER	-	-	629	1,257	-	5000
NASS RIVER	KWINYARH CREEK	-	-	46	129	-	300
NASS RIVER	KWINYIAK RIVER	-	933	342	269	100	3500
NASS RIVER	MCKNIGHT CREEK	-	-	112	268	65	1000
NASS RIVER	MEZIADIN RIVER & LAKE	-	750	2,256	2,725	2,308	7500
NASS RIVER	NASS MAINSTEM	-	-	111	767	-	1000
NASS RIVER	OWEEGIE CREEK & LAKE	-	-	213	417	6	1000
NASS RIVER	QUILGAUW CREEK	-	-	41	36	-	200
NASS RIVER	SEASKINNISH CREEK	559	1,808	738	280	15	3500
NASS RIVER	SNOWBANK CREEK	-	-	45	275	-	700
NASS RIVER	TCHITIN RIVER	-	-	35	50	250	500
NASS RIVER	TEIGEN CREEK	-	-	-	17	-	50
NASS RIVER	TSEAX RIVER	2,173	5,525	5,756	4,600	1,000	15000
NASS RIVER	TSEAX SLOUGH	-	-	-	525	417	2000
NASS RIVER	VAN DYKE CREEK	-	-	15	64	-	150
NASS RIVER	VETTER CREEK & SLOUGH	-	-	281	18	-	2500
NASS RIVER	WEGILADAP CREEK	-	-	30	38	-	100
NASS RIVER	WILYAYANOOTH CREEK	-	-	-	101	-	500
NASS RIVER	ZOLZAP CREEK	35	544	347	583	1,043	2438
NASS RIVER	ZOLZAP SLOUGH	-	-	131	358	-	600

Table 1 (continued).

SUBAREA	STREAM NAME	Mean 1950-59	1960-69	1970-79	1980-89	1990-99	Maximum Recorded
PORTLAND INLET	KHUTZEYMATEEN RIVER	1,245	544	1,064	3,970	4,350	10000
PORTLAND INLET	KWINAMASS RIVER	935	7,025	4,444	3,605	2,600	20000
PORTLAND INLET	LIZARD CREEK	-	-	-	-	-	-
PORTLAND INLET	MANZANITA COVE CREEK	-	-	29	-	-	200
PORTLAND INLET	TSAMPANAKNOK BAY CREEK	-	-	-	2	-	20
WORK CHANNEL	ENSHESHESE RIVER	408	-	525	1,220	1,850	3500
WORK CHANNEL	LACHMACH RIVER	-	289	250	527	1,010	2500
WORK CHANNEL	LEVERSON LAKE SYSTEM	490	188	325	13	-	1500
WORK CHANNEL	TOON RIVER	416	683	669	89	-	2500
COASTAL	AMERICAN BAY CREEK	-	-	-	1	-	12
COASTAL	BRUNDIGE CREEK	-	-	-	12	-	50
COASTAL	SANDY BAY CREEK	-	-	-	3	-	20
COASTAL	STUMAUN CREEK	-	75	-	3	-	750
COASTAL	TRACY CREEK	75	-	-	-	-	75
COASTAL	TURK CREEK	75	-	200	-	-	200
SUBAREA TOTAL: PORTLAND CANAL		1,005	6,533	2,190	1,848	306	19500
SUBAREA TOTAL: OBSERVATORY INLET		2,103	1,230	1,515	2,171	300	10000
SUBAREA TOTAL: NASS RIVER		3,368	16,540	17,188	20,054	5,565	36725
SUBAREA TOTAL: PORTLAND INLET		2,180	7,515	4,765	7,577	5,650	20400
SUBAREA TOTAL: WORK CHANNEL		1,230	783	1,300	1,762	2,860	5000
SUBAREA TOTAL: COASTAL		23	75	20	12	-	750
AREA 3 TOTAL		9,908	32,675	26,978	33,424	14,681	81925

and Lower Nass areas, including the continuation of enumeration programs at Zolzap Creek and Lachmach Creek; while mark-recapture estimates were refined for the Upper Nass aggregate.

The mark-recapture estimate for Upper Nass Area serves as the escapement estimate for that aggregate of coho stocks while a "scaling" approach is used for estimating the total return to Canada for Coastal and Lower Nass Area coho. Annual escapements are derived by expanding escapement estimates from indicator stocks in the Coastal Nass Area and the Lower Nass Area in proportion to system specific and total area estimates of the number of spawners required to maximize smolt production (S_{max}). This "scaling" approach has also been proposed by others. Shaul et al. (2003) suggested that average smolt production could be used as the best estimate of system capability (excluding low escapement years) and that these productivity estimates from full indicator stocks can be scaled to habitat capability estimates for the stock aggregate to generate an overall escapement goal.

A habitat-based approach to quantifying the productive capacity for Area 3 coho production was determined to be the most appropriate approach to establishing escapement reference points at this time. The habitat-based approach to deriving these system specific productivity estimates and total area spawner requirements are described in this paper as the Area 3 Coho Production Model.

AREA 3 COHO PRODUCTION MODEL

The Area 3 Coho Production Model is a habitat-based model that predicts maximum smolt abundance for each stream and the number of spawners that is required to produce the maximum smolt abundance (S_{max}), using the length of stream available for coho rearing as the predictor variable. The model first calculates the total length of stream that is accessible coho for 102 watersheds in Statistical Area 3 using stream gradient, known barriers and stream order (Strahler 1957). A relationship between smolt yield and stream length was then developed using two different approaches. The first approach used a log-linear model to predict smolt yield from stream length using smolt production data from Southeast Alaska and British Columbia (circa 1950-present). In the second approach, recent ten-year mean smolt production measures for three northern BC coho indicator stocks (Lachmach, Zolzap, Toboggan) were used and the average smolts produced per kilometre of stream for these systems was applied to Area 3 coho streams on a sub-regional basis.

Using estimates of survival by life stage, the model then calculated the number of spawners that would be required to produce the estimated number of smolts. Model estimates of smolt production and the required number of spawners were compared to empirical data collected for a subset of the 102 watersheds that were included in the model. Inter-annual variability in smolt production was incorporated into both models and hence into the smolt predictions for Area 3 streams.

The coho production model carries with it the critical assumption that stream length of stream orders greater than 2 (at 1:20,000 scale) is a valid surrogate measure for the limiting habitat available to coho pre-smolts and ultimately limits the amount of smolts produced by the system. This assumption is supported by the fact that there is a downstream movement of fry during fall and winter freshets to occupy lower areas of streams as pre-smolts (Cederholm and Reid 1987). A portion of coho fry migrating downstream may also exit the freshwater environment either passively due to environmental clues (e.g. flooding, freeze-up) or actively due to territorial displacement (Bilby and Bisson 1987, Hartman et al. 1981). The number of smolts emigrating from the stream after one or more years of freshwater residency is therefore assumed to be a function of the number of fry that survive to become parr in their first year of freshwater residency. The limiting factor for maximizing steelhead production is often cited as the availability of suitable habitat at the parr stage (Ptolemy et al. 2004).

The Area 3 Coho Production Model also assumes then that this production bottleneck occurring during the parr-smolt stage of freshwater life for coho is primarily a function of available suitable riverine habitat for yearling coho (hereafter referred to as pre-smolts). To the authors' knowledge, there have been no attempts to quantify any relationship between the amount of late summer or winter rearing habitat available to coho pre-smolts and stream length. However, Sharma and Hilborn (2001) did find that lower valley slopes, lower stream gradients, and pool and pond densities were correlated with higher smolt densities.

DATA SOURCES AND MODEL INPUTS

Coho Distributions

The Fisheries and Oceans catalogue of salmon streams and spawning escapements (Hancock and Marshall 1984) and the Stream Summary Catalogue (DFO 1991) were used to develop a list of all coho-bearing streams in Statistical Area 3 (Appendix **A**). Streams for which the topography suggested no reason why coho would not be present were also included. For the most part, these were watersheds in the upper Nass River drainage where information on coho distributions was extremely limited or nonexistent.

Van Schubert (1999) conducted fish reconnaissance surveys in areas of the Nass watershed upstream of the confluence of Damdochax Creek in late September of 1998. No anadromous salmon with the possible exception of steelhead were identified in any of the sites sampled. Based on these results, the entire Nass drainage upstream of Damdochax Creek was considered to have zero coho potential, even though small amounts of each tributary appear to be accessible to anadromous salmon (Van Schubert 1999). Barriers to anadromous fish are present near the mouth of each of these systems.

Streams were categorized based on the sub-region within Area 3 into which their watersheds emptied. The four sub-regions were: Outer Coastal Area 3, Coastal Nass Area, Lower Nass River, and Upper Nass River. The Upper Nass River above Damdochax was treated as a separate tributary and the Kiteen River that empties into the Cranberry was also treated as a separate tributary system. As well, the Bell-Irving River was stratified into upper, middle, and lower sections. The mainstem of the Nass River, below Damdochax was also not included as parr-smolt rearing habitat in the model.

All known coho producing streams from Fisheries and Oceans records were included in the analysis. These watersheds were primarily of 3rd order or greater on 1:20,000 Digital Terrain Resource Information Management (TRIM) mapping (Ministry of Sustainable Resource Management). Although only stream order 2, Manzanita Creek was also included in the analysis because of noted good abundances of coho.

Accessible Stream Length

The length of stream within a tributary accessible to coho is restricted by barriers to migration, gradient, discharge, water quality (dissolved oxygen, turbidity, temperature), as well as evolutionary distribution factors. Waterfalls, debris jams, and excessive water velocities may impede fish access into otherwise suitable habitat. However, assessing whether or not a natural obstruction (e.g., falls, cascade, and chute) is a barrier is not easy. Falls that are insurmountable at one time of the year may be passed at other times under different flows (Bjornn and Reiser 1991). Powers and Orsborn (1985) reported that the ability of salmonids to pass over barriers is dependent on the swimming velocity of adult fish, the horizontal and vertical distances to be jumped, and the angle to the top of the barrier. The pool depth to height ratio is also important (Stuart 1962). Bjorn and Reiser (1991) determined a maximum jumping height for coho of 2.2 m under optimal conditions.

The Area 3 Coho Model used a height estimate of 2.0 m for an obstruction to be considered a barrier to coho. The model also considered that a point along the stream course where gradient exceeded 100% (45^{o}) for longer than 10 metres would also be a barrier to coho migration. Sensitivity analyses were performed on the "run" or length of the stream segment from 1 m to 10 m for a slope of 45^{o}.

All available information on barriers within the Nass drainage was used to restrict coho use in systems. The sources of information on barriers included FISS (1991a, b), Aquatic Biophysical Maps (MOE 1977), unpublished information from the Ministry of Water, Land and Air Protection, and data gathered through Watershed Restoration Program studies (NTC 1994-98) and Fish Inventory Projects (NTC 1998a-h, Van Schubert 1999, Saimoto and Saimoto 1998). The total accessible stream length within each Nass tributary was calculated from digital TRIM files (1:20,000 scale) using ARCINFO and stratified according to gradient and stream order. Where lakes were present within the network of accessible stream, the length of centre lines connecting accessible lake tributaries to the lake outlet was included in the total length calculation. This had the net effect of including a portion of the lake something less than the perimeter as suitable habitat for coho parr.

Gradient

Pess et al. (2002) found that coho spawner abundance was correlated with stream gradient in the Snohomish River, Washington. Coho have been reported to occur in stream segments with gradients ranging from one to ten percent, with the greatest densities occurring in the lower gradients. Higher gradient areas are dominated by larger substrate and lack the pool habitat favoured by coho for rearing (Bisson et al. 1982). The Area 3 Coho Model assumed that stream gradients over 8% were not utilized by coho parr or pre-smolts for rearing and that all gradients below 8% had similar density of coho. ARCINFO and a gradient analysis program were used to calculate the accessible length of stream within each watershed. For sensitivity analyses, accessible area was determined for upper gradient limits of 2%, 4%, 6% and 8%.

Stream Order

Stream orders were determined using a method developed by Horton (1945) and later modified by Strahler (1957) and were determined from the BC TRIM digital mapping (1:20000 scale). The analysis allowed for the summation of accessible length for stream orders greater than 3 and determination of the proportional contribution of 3^{rd} order or larger streams.

The Area 3 Coho Model also assumed that coho would not occupy stream habitats more than two stream orders distance from the main stem. For example, for large streams of order 7, the minimum stream order included for that watershed was 5. Figure 2 schematically illustrates this algorithm.

$$\text{Order}_{\text{used}} = \text{order}_{\text{wshd}} - B \qquad \text{equation (1)}$$

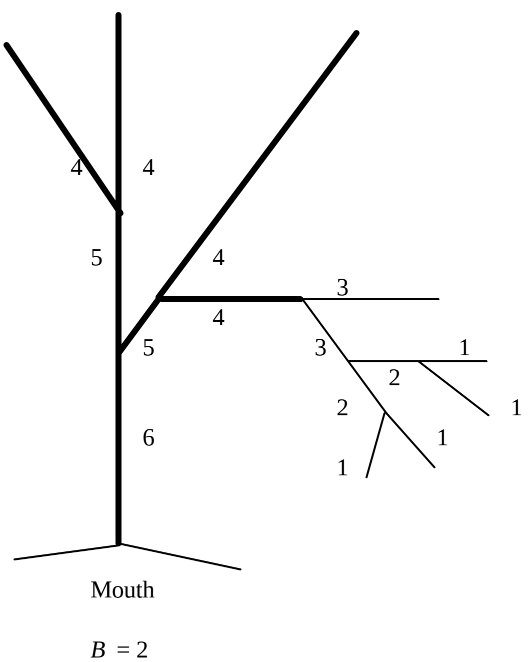

Figure 2. Schematic drawing of how stream order was used to determine accessible length using different values of B (see equation 1). Bold areas indicate streams included in the analyses. Numbers indicated stream order.

Mean Smolt Yield

Model 1

The first model for smolt yield used a large geographic data set to determine the smolt yield per kilometre of stream. Annual yield of coho smolts and the associated accessible stream length were compiled for all Alaska, BC, Washington and Oregon streams from Bradford et al. (1997) (Appendix B). The mean coho smolt yield was calculated for streams with three or more annual estimates. Streams were then classified, *a priori*, into the following three geographical groups:

(1) Alaska and Northern BC; (2) Southern BC; and (3) Washington and Oregon. This grouping was based on evidence of lower productivity (smolts produced per unit length) for southern streams. Alaska and Northern BC streams were combined to maintain a reasonable sample size of 9 streams (albeit still a small number). The Keogh River on northern Vancouver Island was the most northerly of the Southern BC streams (Appendix B).

The effects of geographical groups and stream length on yield of smolts were examined using analysis of covariance following Milliken and Johnson (2002). The smolt yield and stream length were logarithmic transformed to obtain homogeneous variance residuals. The analysis consisted of the application of two covariance models. The first was as follows:

$$\ln\{\text{smolt yield}\} = \text{constant} + \text{group} + \ln\{\text{stream length}\} + \text{group}*\ln\{\text{stream length}\} \quad \text{equation (2)}$$

where group is a categorical variable coded to the geographical groups defined above. The interaction term (group*ln{stream length}) was tested for significance. This interaction term represents the slopes of the regression lines of ln{yield} on ln{stream length}. Since the interaction term was not statistically significant (see Results below), a simpler second model without the interaction term was employed:

$$\ln\{\text{smolt yield}\} = \text{constant} + \text{group} + \ln\{\text{stream length}\} \qquad \text{equation (3)}$$

The group term now represents the relative mean ln{smolt yield} for parallel regression lines at any given stream length value (e.g., the intercept). The group term was tested for significance and the orthogonal contrasts (the group term partitioned into two single degree of freedom contrasts) were calculated. The two contrasts considered were:

1. Alaska and Northern BC (group 1) combined with Southern BC (group 2) versus Washington and Oregon (group 3); and
2. Alaska and Northern BC (group 1) versus Southern BC (group 2).

A predictive regression model for all Nass region streams was then constructed combining all groups not significantly different from Alaska and Northern BC (group 1). Predictions of log-transformed smolt yield and the associated variance were then made given the stream length using the well known predictive regression functions (e.g., Draper and Smith 1981). The arithmetic expectation and variance for smolt yield was next calculated assuming a log-normal distribution using:

$$E[Y] = \exp\{\hat{\mu} + \hat{s}^2 / 2\} \qquad \text{equation (4)}$$

and

$$Var(Y) = \exp\{2\hat{\mu} + \hat{s}^2\}(\exp\{\hat{s}^2\} - 1) \qquad \text{equation (5)}$$

where $\hat{\mu}$ is the mean and $\hat{s}^2$ is the variance of the logged transformed predictions (Johnson and Kotz 1970). Assuming the stream predictions are independent, the mean for the area is the sum of the mean of the component streams. Thus, the predicted means were summed for each watershed in the Nass region. The variance terms for each component stream can be similarly summed to get area-wide variance values. The summed mean and variance estimates can be regarded as normally distributed according to the central limit theorem.

Model 2

The second model for smolt yield used the mean (1991-2000) annual smolt yield per kilometre for Lachmach, Zolzap, and Toboggan applied to Area 3 streams. Lachmach smolt yield was applied to all coastal areas of Area 3; Zolzap smolt yield was applied to all lower Nass tributaries; and Toboggan Creek smolt yield was applied to all Upper Nass systems. Variability around these estimates was estimated using the observed variability for Lachmach, Zolzap and Toboggan.

Required number of Spawners

Determining the number of spawners required to produce a given number of smolts involved back calculating from the smolt estimate to spawners using fecundity and survival estimates. Limited data for coho sex ratios are available for Statistical Area 3 streams. The average sex ratio of adult coho passing the counting weir at Zolzap Creek from 1998-2000 was 1.03 (M/F; Table 2). Sex ratio for the purposes of calculating the number of spawners required in the model was, therefore, assumed to be 1.0.

Table 2. Sex ratio of coho spawners observed at the Zolzap Creek counting fence, 1998-2002 (from Baxter 2003; Baxter and Stephens 2002, 2002a, 2002b; and Baxter et al. 2001).

Year	Males	Females	Ratio (M/F)
1998	517	437	1.18
1999	713	574	1.24
2000	188	217	0.87
2001	1,076	816	1.32
2002	753	1111	0.68
All Years	3,247	3,155	1.03

Fecundity

The required number of spawners to fully seed the available habitat was determined for each stream using estimates of fecundity. The number of eggs per female for Outside Area 3 coho was estimated using data from Lachmach River; for the Coastal Nass Area data from Kincolith River was used; and for the Lower and Upper Nass Area data from Zolzap Creek and Tseax River were used. Direct measures of fecundity were only available for Kincolith River and Tseax River. For Lachmach River, length data from the 1989 brood were used to calculate fecundity as:

$$\text{Eggs per Female} = 1.8933\,(\log(FL)) - 1.8612 \qquad \text{equation (6)}$$

where FL = female fork length at maturity.

The same equation was used for Zolzap Creek to convert female length data from 1996-99 to an estimate of fecundity. The fecundity estimate for Lachmach was 2,906 eggs per female based on an average length of 649 mm for the 1989 brood (Joel Sawada, DFO, pers. comm.). Fecundity estimates for Kincolith coho, obtained from hatchery broodstock collections in 1995 and 1996 (Richard Alexander, pers. comm.), averaged 3,736 (n = 64). Recognizing inter-stream variability in fecundity and to be conservative, a fecundity of 3,000 eggs per female was used in the model for all Outer Coastal Area 3 and Coastal Nass Area streams.

The fecundity estimate for Zolzap Creek coho ranged from 2,461 to 2,931 for brood years 1996-1999 with a mean of 2,629. The average fecundity for Tseax River coho (1993-94) was 2,500 eggs per female. Therefore, for simplicity, a fecundity of 2,500 eggs per female was used in the model for all Lower Nass Area and Upper Nass Area streams.

Freshwater Survival

Freshwater survival estimates for coho salmon are only available for Zolzap Creek in the Lower Nass Area. Therefore, an egg-to-fry survival of 19.8% and a fry-to-smolt survival of 7.6% (Bradford 1995) were used to calculate the number of spawners required to produce the estimated smolt yield for each stream and area. This translates to an overall egg-to-smolt survival of 1.5%. This survival is similar to survival observed at Zolzap Creek (1.6%) for the 1992 to 1998 broods (Table 3).

Table 3. Egg-to-smolt survivals for Zolzap Creek coho, 1992-1998 broods (data from Baxter et al. 2001).

Brood Year	Spawners	Females	Eggs	Smolts Recruited	Egg-to Smolt Survival
1992	1,561	781	2,341,500	17,306	0.7%
1993	1,048	524	1,572,000	13,396	0.9%
1994	2,536	1,268	3,804,000	23,116	0.6%
1995	908	454	1,362,000	19,669	1.4%
1996	1,039	520	1,558,500	17,701	1.1%
1997	470	235	705,000	10,641	1.5%
1998	967	484	1,450,500	41,292	2.8%
Mean	1,218	609	1,827,643	20,446	1.3%

Sensitivity Analyses

Sensitivity analyses were performed on a number of model parameters to explore the sensitivity of predicted smolt yield and required spawner numbers to those parameters. The parameters tested were gradient barrier criteria, stream order (*B* value), gradient criteria for rearing, egg-to-fry survival, and fry-to-smolt survival. Fecundity estimates were not evaluated in the sensitivity analyses.

MODEL RESULTS

Distribution of Nass Coho Habitat

Figure 3 shows the distribution of Area 3 coho habitat as determined by the model. Coho habitat in Area 3 is widely distributed among the 102 streams. There are a few major producers in each area (e.g., Khutzemateen, Bear, Kwinamass, Ishkeenickh, Bell Irving, Kwinageese and Cranberry).

Accessible Stream Length

Estimated accessible lengths for all Area 3 streams are provided in Figure 3 and Appendix A. All model estimates of accessible stream length were based on an upper gradient limit of 8% and a *B* of 2 for the stream order determination.

Mean Smolt Yield

Model 1

Figure 4 provides the regression plots of smolt yield versus stream length for the three geographical groups. The results of the covariance analysis and orthogonal contrasts are listed in Table 4. Note that the regression slopes can be viewed as equal (P=0.324) and the simpler covariance model (parallel lines) indicates that the groups are significantly different (P<0.001). The orthogonal contrasts indicate that Washington and Oregon are substantially different than the other two groups combined (P<0.001) while there is little difference between the Alaska and Northern BC (group 1) and Southern (group 2) groups (P=0.427).
Table **5** lists the adjusted least square log-transformed means (at the mean stream length) of the geographical groups.

The regression plots with the significantly different groups (Alaska and BC combined) are provided in Figure 5. The predictive regression used for the Nass region was then:

$$\ln(\text{smolt yield}\} = 7.87868 + 0.83923 * \ln\{\text{stream length}\} \qquad \text{equation (7)}$$

$$R^2 = 0.70$$

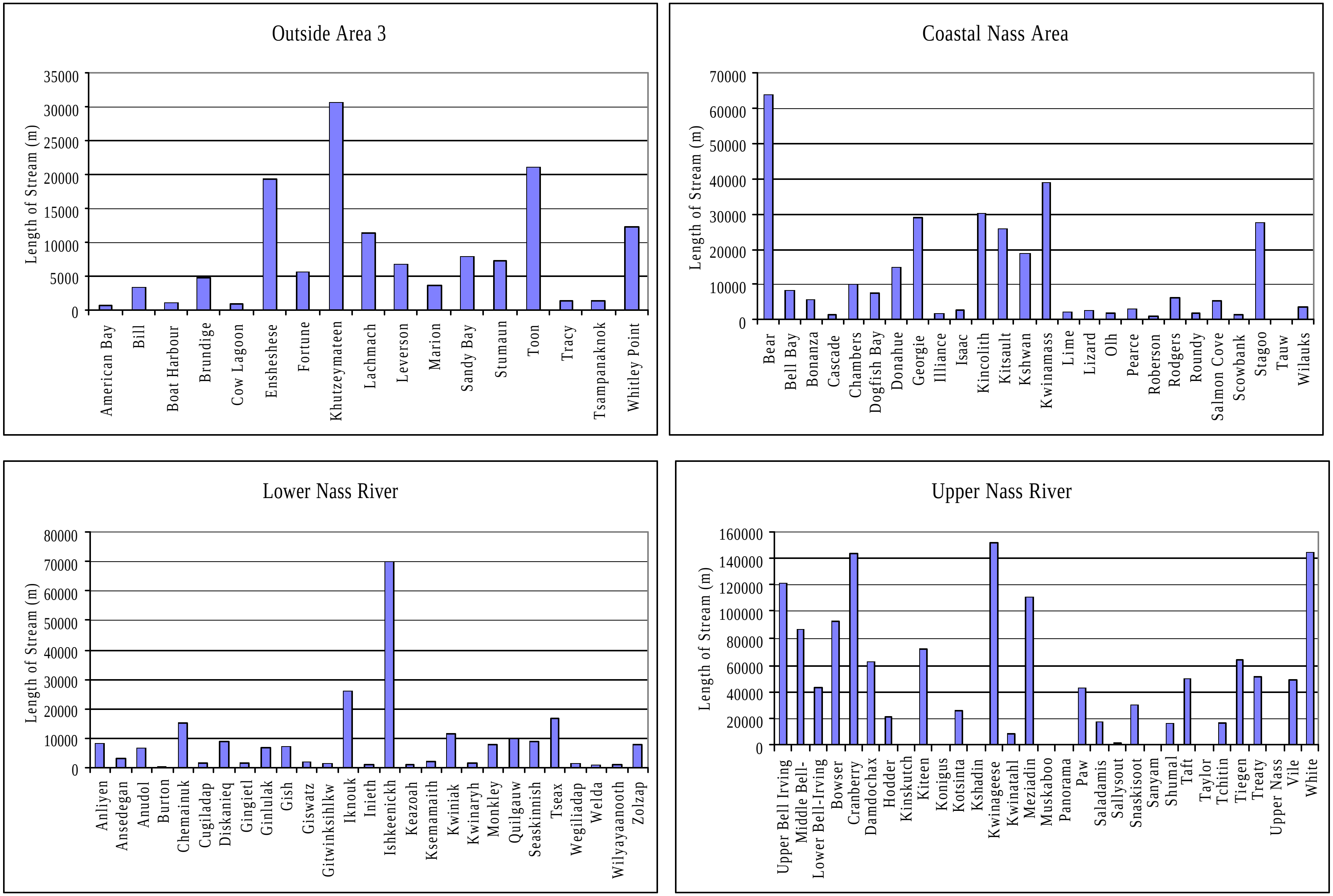

Figure 3. Distribution of coho habitat as measured by accessible stream length less than 8% gradient and B = 2 for stream order equation (1) within Statistical Area 3.

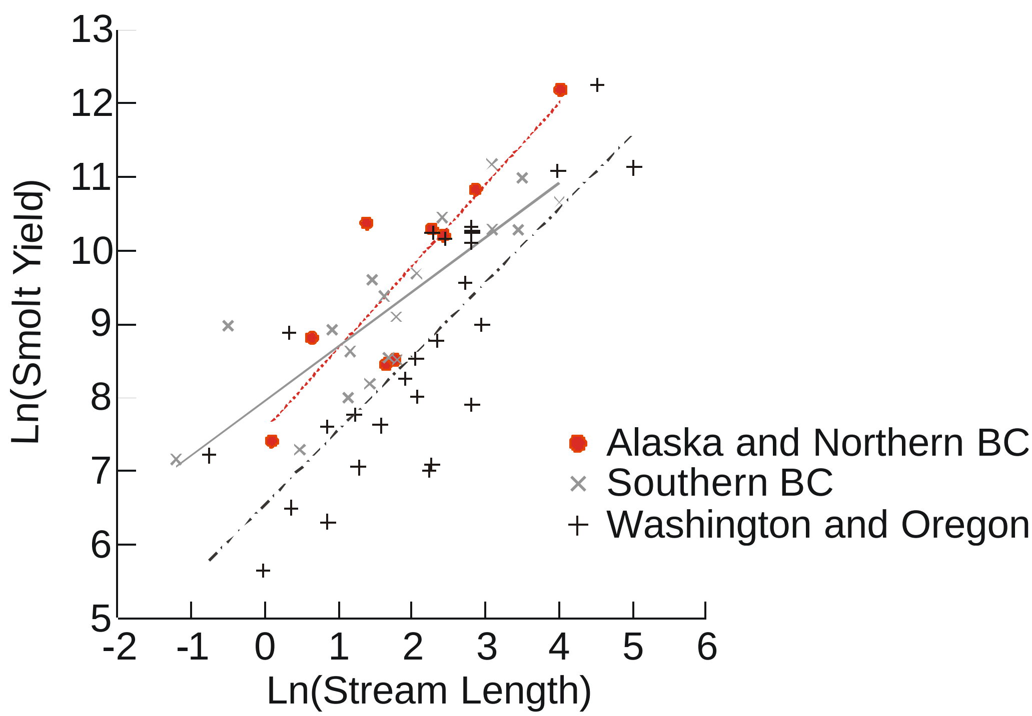

Figure 4. Smolt yield as a function of stream length (km) by geographic group.

Table 4. Analysis of covariance sum of squares (SS), degrees of freedom (df) and hypotheses tests.

Component	SS(Test)	df(Test)	SS(Error)	df(Error)	F	Probability
Slopes	1.78	2	37.12	48	1.15	0.3241
Groups	14.04	2	38.90	50	9.02	0.0005
1&2 vrs 3	13.54	1	38.90	50	17.41	0.0001
1 vrs 2	0.50	1	38.90	50	0.64	0.4266

Table 5. Adjusted least square means by geographic group.

Group	N	Adj. Mean	Std. Error
Alaska and Northern BC	9	9.702	0.294
Southern BC	19	9.416	0.203
Washington and Oregon	26	8.501	0.173

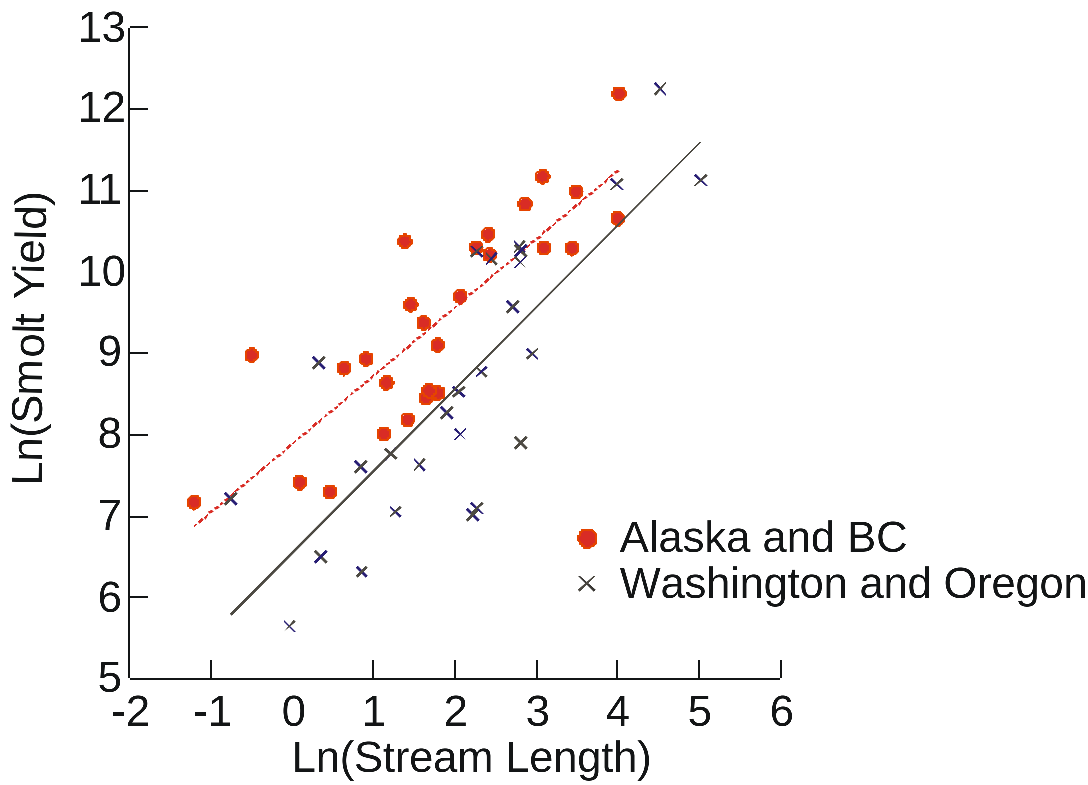

Figure 5. Smolt yield as a function of stream length (km) by significantly different geographic groups.

Model 2

At the time of this study, annual smolt yields for Lachmach, Zolzap and Toboggan creeks were available from the early 1990s to 2000 (Figure 6, Figure 7, and Figure 8). Means over the period 1990 to 2000 were 27,163 smolts for Lachmach, 29,833 for Zolzap and 50,724 for Toboggan. As such, average smolt yields per kilometre were 2383, 3088, and 2892 for Lachmach, Zolzap and Toboggan respectively. Mean smolt yield for Lachmach was applied to Outer Coastal Area 3 and the Coastal Nass Area streams; mean smolt yield for Zolzap was applied to the Lower Nass Area streams; and mean smolt yield for Toboggan was applied to Upper Nass Area streams.

Predicted Smolt Production

The predicted smolt production by stream for each of the two models is provided in Appendix C. Area totals with standard deviations are summarized in Table 6 and Table 7 and displayed in Figure 9. Model 1 used region-wide estimates over a 40 year time period, while Model 2 used area-specific

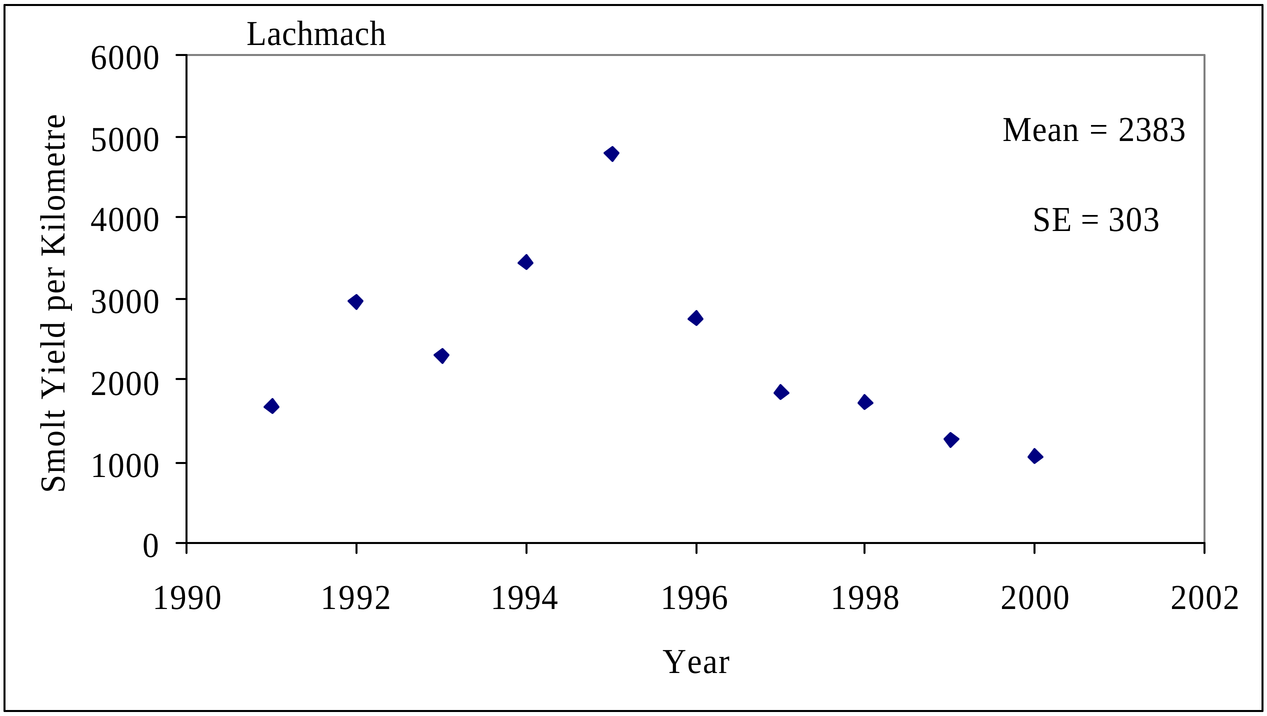

Figure 6. Smolt yield per kilometre for Lachmach Creek coho, by smolt year.

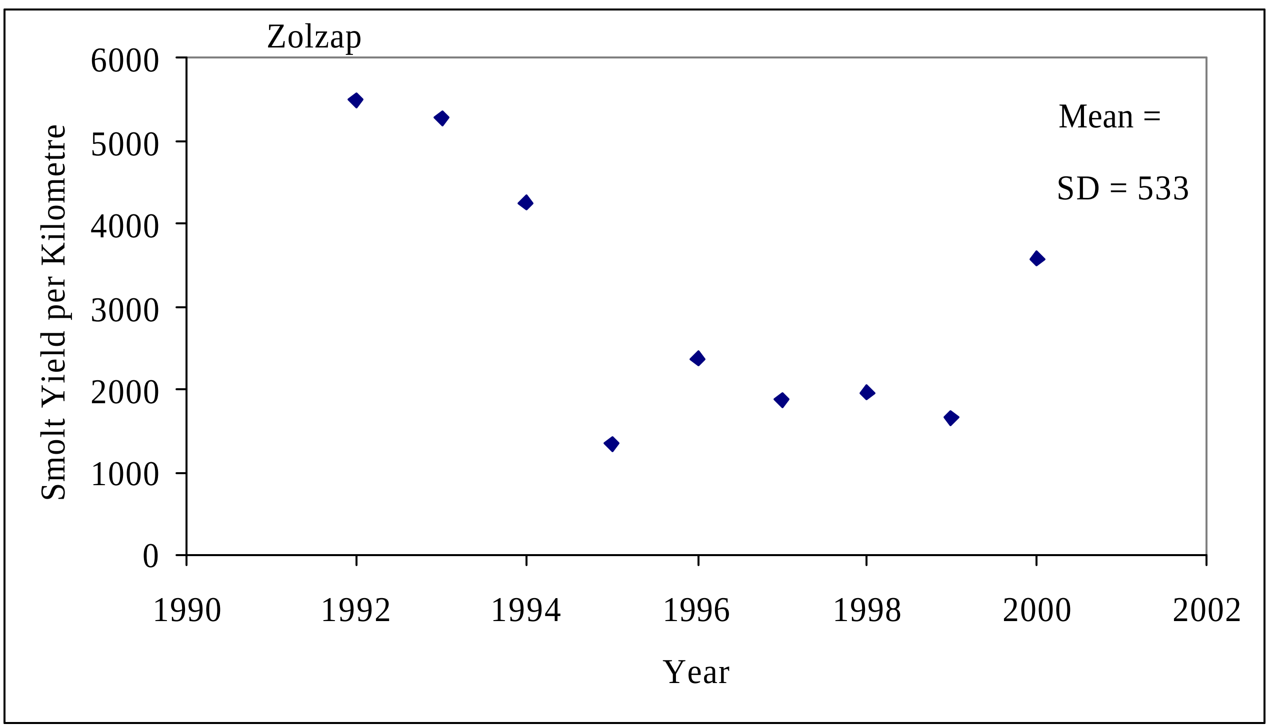

Figure 7. Smolt yield per kilometre for Zolzap Creek coho, by smolt year.

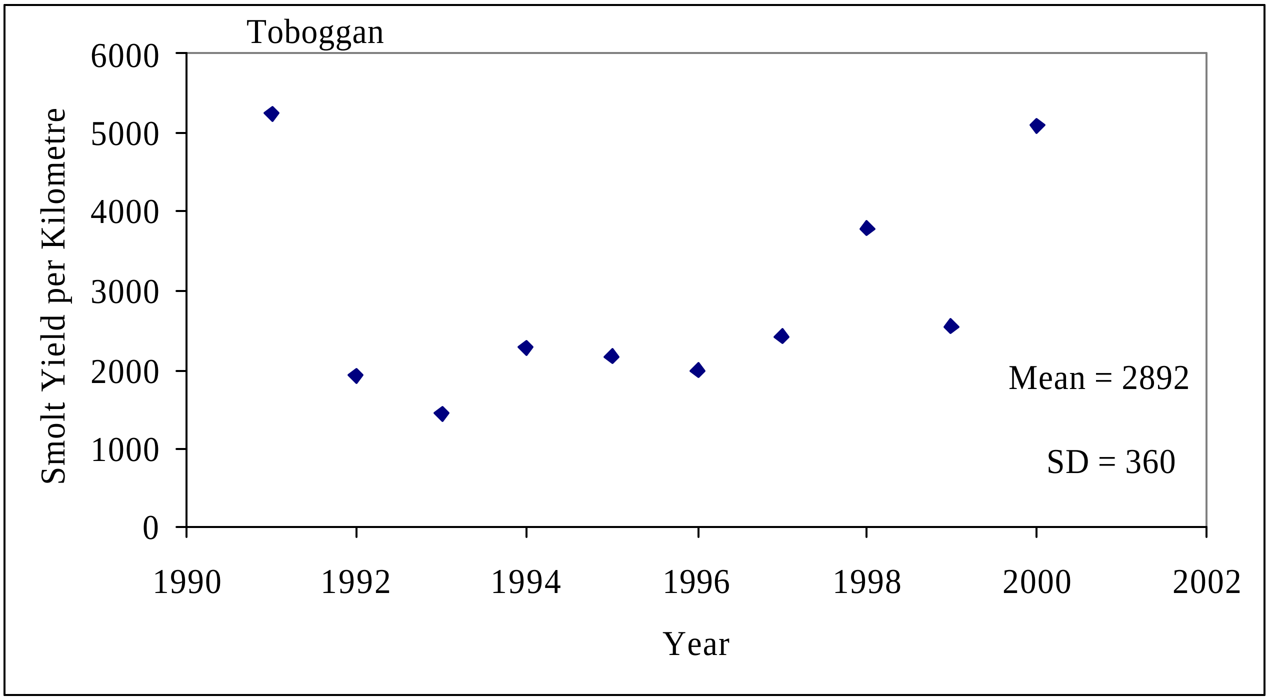

Figure 8. Smolt yield per kilometre for Toboggan Creek coho, by smolt year.

Table 6. Model 1 predicted coho smolt output by Area 3 regions for gradient less than 8% and *B* parameter = 2, using region-wide regression. Prediction equation is ln (smolt yield) = 7.879 + 0.839*ln (length).

Sub Area	N	Mean	SE
Outside Area 3	18	339,441	20,940
Coastal Nass Area	26	672,516	33,118
Lower Nass River	27	505,125	27,053
Upper Nass River	31	2,532,001	104,704
Total	102	4,049,084	62,310

Table 7. Model 2 predicted coho smolt output by Area 3 regions for gradient less than 8% and *B* parameter = 2, using Lachmach, Zolzap, and Toboggan mean smolt yields.

Sub Area	N	Mean	SE
Outside Area 3	18	347,686	12,925
Coastal Nass Area	26	750,650	21,940
Lower Nass River	27	700,126	25,405
Upper Nass River	31	4,132,428	88,966
Total	102	5,930,890	52,236

Table 8. Spawner requirements to produce predicted coho smolt yield for Area 3 streams. (95% Confidence Limits are carried forward from smolt estimation confidence limits with no variance added to account for uncertainty in survivals and fecundity).

	Model 1			Model 2		
Region	Estimate	95% CL		Model 2	95% CL	
Outside Area 3	5,038	13,081	16,996	15,444	14,233	16,655
Coastal Nass	29,794	26,772	32,817	33,344	31,409	35,278
Lower Nass	26,854	23,897	29,811	37,319	34,535	40,103
Upper Nass	134,609	123,243	145,976	220,273	209,699	230,847

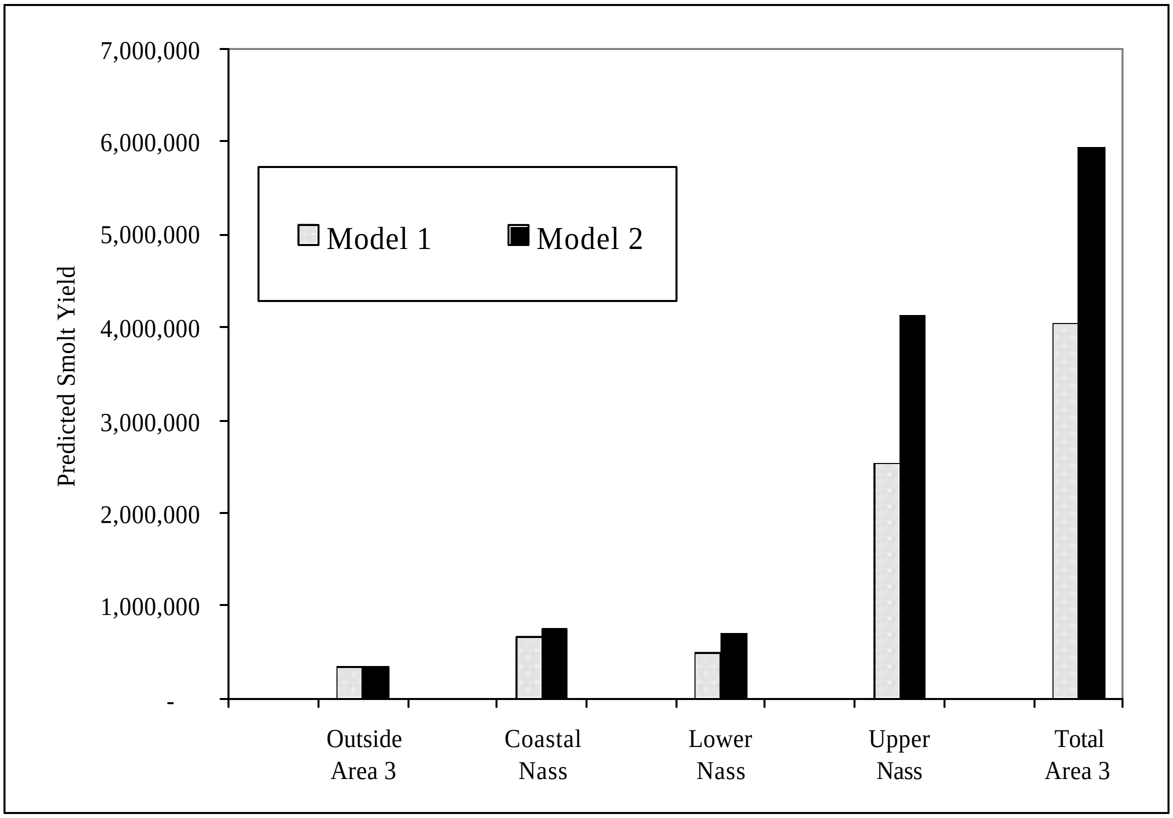

Figure 9. Comparison of predicted smolt yield estimates for sub-regions in Area 3 using the two different smolt yield models.

measures over a recent ten-year period. Model 2 estimates of smolt production were higher than for Model 1, particularly for the Lower Nass and Upper Nass areas. 95% confidence intervals on the area-specific estimates of smolt yield are shown in Figure 10.

Predicted Spawner Requirements

Figure 11 and Table 8 (see also Appendix D and Appendix E) show estimates of the number of spawners required to produce the number of smolts calculated by the two models. As a result of higher estimates smolt yields, Model 2 produced higher numbers of required spawners than Model 1, particularly for the Lower and Upper Nass areas. Confidence limits on the predicted spawner abundances are also shown in Table 8, but these do not include the considerable uncertainty associated with the survival parameters used to back-calculate required spawners from the predicted smolt yield.

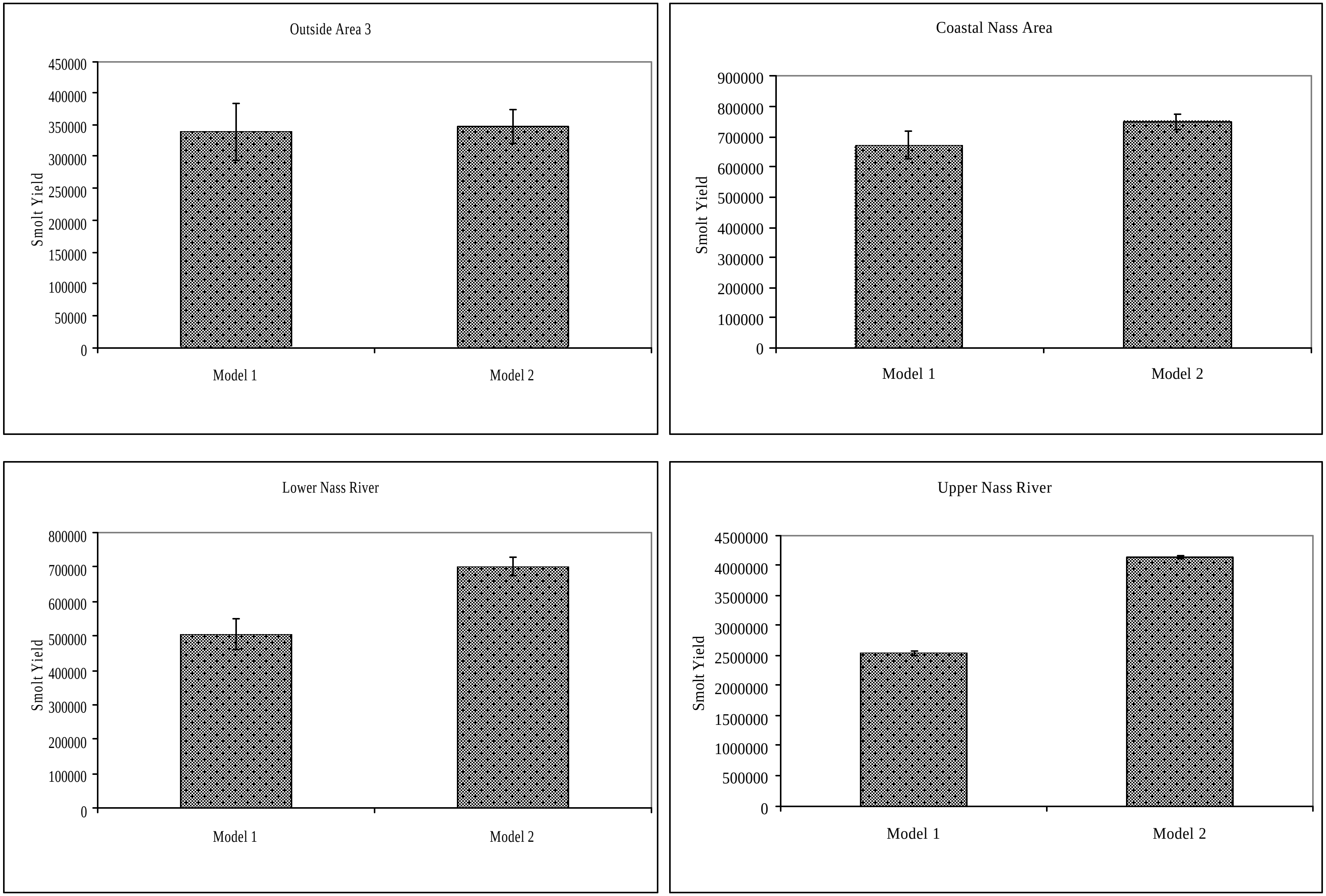

Figure 10. 95% confidence intervals for the prediction of smolt yield from accessible stream length for Statistical Area 3.

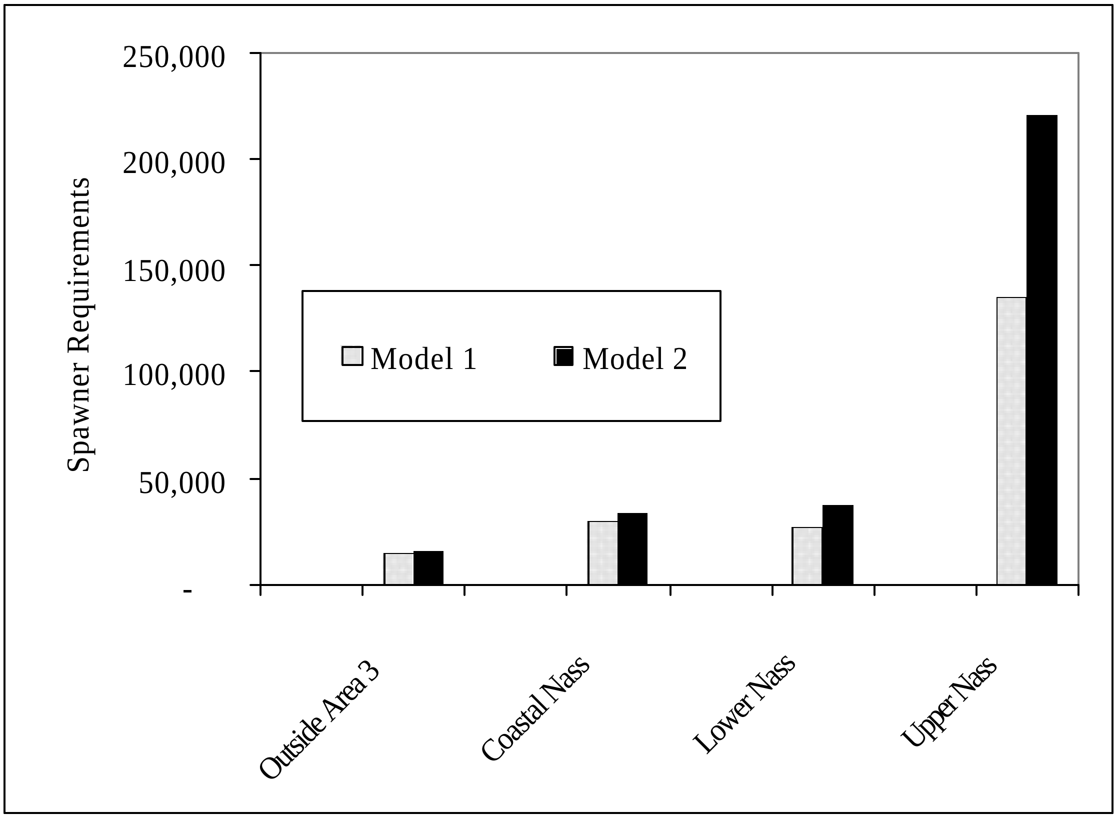

Figure 11. Estimated spawning requirements to produce predicted smolt yield in Statistical Area 3.

SENSITIVITY ANALYSES

All sensitivity analyses were conducted using output from Model 1.

Accessible Stream Length Determinations

The determination of accessible coho area is the first point where error can be introduced to the model. In the model, we used known barriers (where available) as the upper limit of coho accessibility in each watershed. However, for many systems, barriers are unknown or the upper limit is determined by stream gradient. We used a stream gradient of 100% (45°) for greater than 10 m (i.e., a rise of 10 m over 10 m) as a gradient barrier to coho. We compared the total accessible length of stream (3rd order or greater) for Area 3 using 100% for various lengths of stream segment in the TRIM database (Table 9). Changing the length of the "gradient barrier" had little effect on the total amount of accessible habitat for the entire Area 3 aggregate.

Reducing the gradient barrier length from 10 m to 1 m resulted in only a reduction of 0.67 % in the total available length of stream for coho.

Table 9. Comparison of the total length of stream habitat available to coho in Statistical Area 3 using 100% slope for different lengths of stream as a gradient barrier.

	Length of Stream Segment (km)			
	10 m	5 m	2 m	1 m
3rd Order and greater	3,898,080	3,898,080	3,897,620	3,872,160
% difference		0%	0.01%	0.67%

To test model sensitivity to the 8% gradient used as the upper limit of coho distribution (pres-smolt rearing habitat) and the stream order algorithm used, the model was run using upper gradient limits ranging from <2% to <8%. The model was also run using *B* parameters ranging from 1 to 3 (see equation 1 and Figure 2). Note, that as *B* increases, the number of tributaries off the mainstem included in the model increases, hence the length of useable stream habitat increases. Similarly, decreasing the upper gradient limit for accessibility decreased the estimate of accessible length.

The model was fairly robust over the range of gradient and *B* parameter tested and was more sensitive to *B* than gradient (Figure 12). Errors in gradient and *B* had the most pronounced effect on the predicted spawner requirements for the Upper Nass area where terrain relief was lowest. Changing the upper gradient limit to 2% from 8% resulted in roughly a 25% decrease in the estimate of accessible stream length for the *B* values tested (Table 10). The sensitivity to *B* was more pronounced, particularly for the Upper Nass area where changing the *B* value for the stream order network from 1 to 3 resulted in a 48-58% increase in the length of stream accessible to coho and a significant change in the number spawners predicted.

Table 10. Estimated accessible length (m) over a range of gradient limits and stream order values (*B*). Italicized numbers are percent difference for gradient <2% / *B*=1 and gradient <8% / *B*=3.

Area	Gradient	B			
		1	2	3	% Difference
Outer Coastal Area 3	<8%	134070	145920	173680	23%
	<6%	127940	139240	165060	22%
	<4%	118940	129580	152640	22%
	<2%	103270	113280	132700	22%
	% Difference	23%	22%	24%	
Coastal Nass	<8%	223140	315040	355780	37%
	<6%	207800	296260	331630	37%
	<4%	191250	274820	304780	37%
	<2%	167400	242020	266800	37%
	% Difference	25%	23%	25%	
Lower Nass	<8%	199290	226700	272430	27%
	<6%	191740	217650	257160	25%
	<4%	180960	203110	234270	23%
	<2%	155810	170690	190190	18%
	% Difference	22%	25%	30%	
Upper Nass	<8%	888500	1428970	2098070	58%
	<6%	858210	1365800	1941570	56%
	<4%	815410	1263190	1722510	53%
	<2%	758440	1121380	1461120	48%
	% Difference	15%	22%	30%	

Freshwater Survival

The model was also tested for sensitivity to the freshwater survival values that were used to calculate the required number of spawners (19.8% egg-to-fry survival and 7.6% fry-to-smolt survival). A range of egg-to-fry and fry-to-smolt survivals was tested. The model was most sensitive to fry-to-smolt survival (Figure 13), particularly when it was decreased to less than 5% resulting in significant positive error in the required spawners.

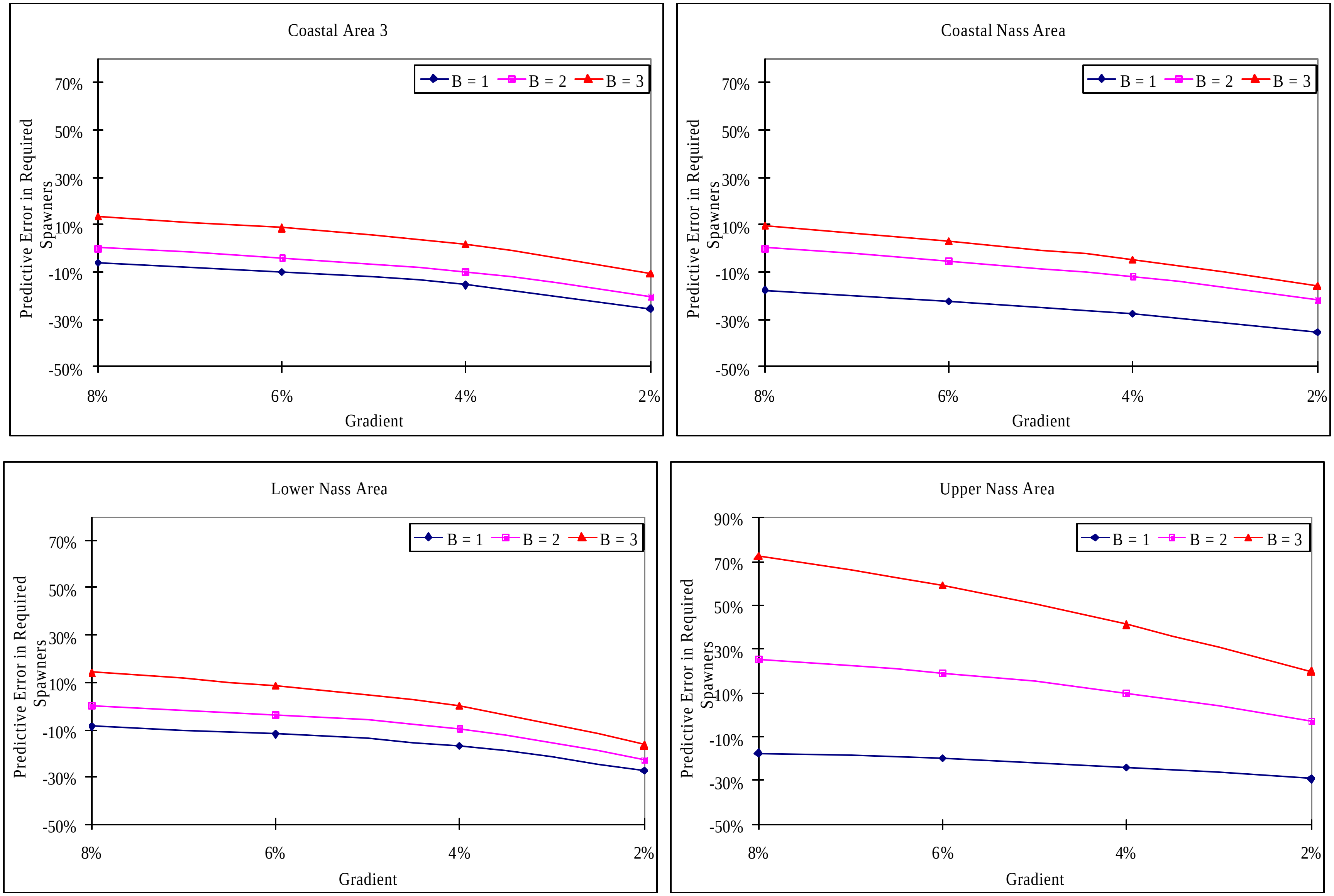

Figure 12. Sensitivity of the predicted spawner requirements to stream gradient and the included stream network (order) as defined by *B* and using Model 1.

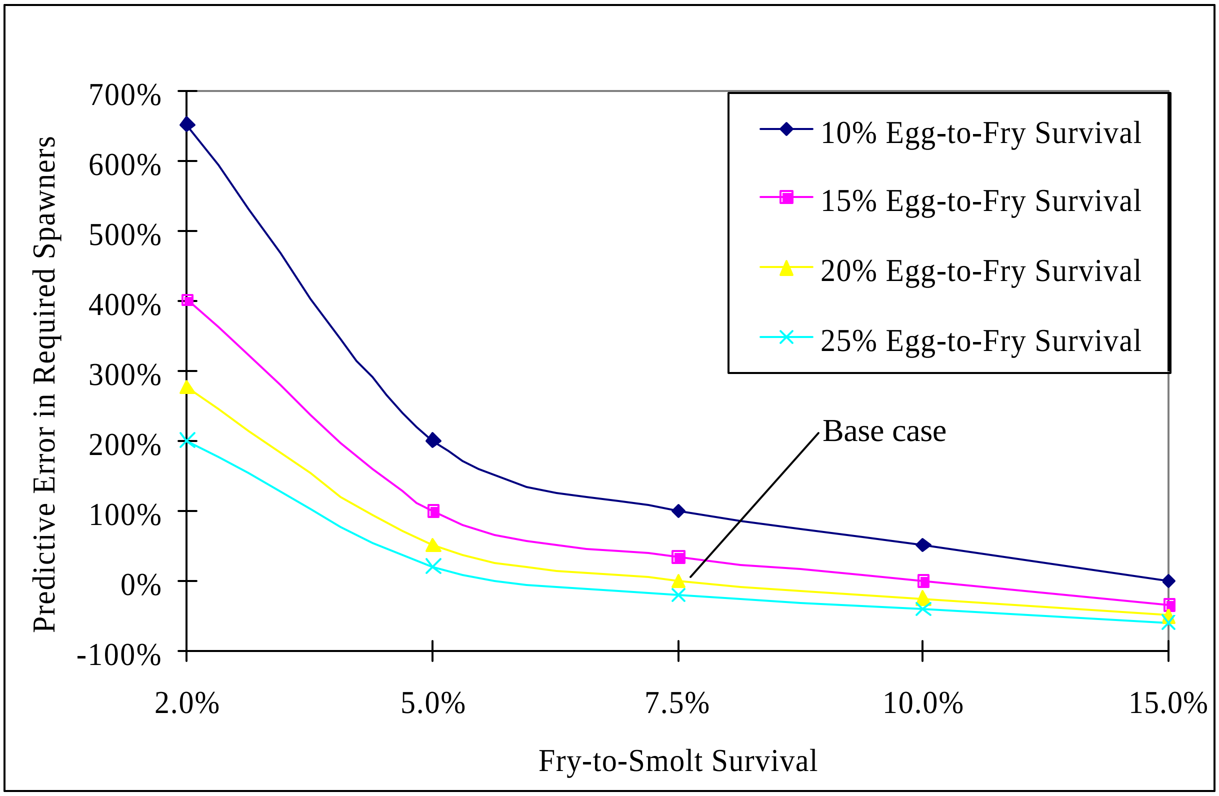

Figure 13. Sensitivity of the predicted spawner requirements to freshwater survival estimates using Model 1.

DISCUSSION

Identification of escapement targets is critical for management of coho salmon in Area 3 and implementation of the Nisga'a Treaty which also requires an estimate of Total Return to Canada (TRC) for the Nass Area each year. The Area 3 Coho Model described here is the first attempt at defining escapement goals for coho in this area. The premise of correlation between smolt yield and stream length is well supported in the literature and the use of the large geographic data set for Model 1 ensures robustness across stream size and type.

Accessible Stream Length

Digital Terrain Resource Information Management (TRIM) maps at a 1:20,000 scale for Statistical Area 3 were used for this model. TRIM maps are derived from air photo interpretation and are considered to be accurate to within 10 m, 90% of the time (Brown et al.

1996). However, tree vegetation makes capture of all waterways difficult from air photos. In an examination of TRIM mapping with ground surveys, Brown et al. (1996) found that TRIM delineated 80% of the natural channel length in basins with terrain relief. The percentage delineated by TRIM in areas of low relief was 73%. The watersheds included in the Area 3 Coho Model have significant terrain relief and TRIM likely captures the majority of the stream network that is accessible to coho salmon.

Effect of Map Scale

Model 1 was derived using region-wide data for smolts/km for which stream length was derived primarily from 1:50,000 or higher scale maps (M. Bradford, pers. comm.), with the exception of Zolzap and Lachmach creeks (Area 3 streams). The stream lengths for Area 3 streams were derived from 1:20,000 scale TRIM maps. Therefore, Model 1 may overestimate the smolt capacity for Area 3 streams due to a mismatch of map scales. However, this would likely be small for the Coastal Area and Lower Nass Area streams where topographic relief is quite high and the accessible stream length determined from 1:50,000 scale versus 1:20,000 scale maps would be similar. Map scale may be more of a concern for some Upper Nass Area streams where relief is lower and additional tributaries (particularly 3rd order), with a significant amount of available coho habitat, may be captured at 1:20,000 scale but not appear on 1:50,000 scale mapping.

Limits to Smolt Production

Coho smolt production appears to be independent of the number of spawners except at low spawner abundances (Bradford et al. 2000, Knight 1980, Holtby and Scrivener 1989). Nickelson et al. (1992) concluded that coho salmon in Oregon are likely limited by the availability of winter habitat (also Brown and Hartman 1988). Furthermore, several authors have documented the downstream movement of coho juveniles from upper watershed areas to lower watershed areas in the fall (Brown et al. 1999, Cederholm and Scarlett 1991). This movement is likely in preparation for smolting and perhaps a response to habitat contraction due to drying or freezing. It is these behaviours, which likely enable the prediction of smolt production from available rearing habitat (e.g., stream length) in the higher order streams within a watershed.

The Nass River and its watersheds are characterized by dramatic fluctuations in flow (Figure 14). There are typically two low flow periods, late summer and winter. Freezing in winter also reduces available habitat in some parts of the Nass watershed. The life stages of salmonids at these critical times (fall fry, and pre-smolts) become the limiting stages to total smolt production. During these times, available habitat to rearing salmonids is contracted and the mainstem and primary tributaries account for a greater proportion of the available and useable habitat. It is this interrelation between critical flow and available habitat that likely allows for stream length to be a reasonable predictor of smolt production.

Required Number of Spawners

The applicability of Model 1 for predicting the number of spawners required to maximize smolt production in Statistical Area 3 carries with it many assumptions. Perhaps foremost, the model assumes that the historical mean smolt data used to derive the model is reflective of smolt productive capacity for the geographic region included (BC and Alaska). Although this is consistent with the thinking of previous researchers; namely that average smolt production is an appropriate measure of capacity (Marshall and Britton 1990, Bradford et al. 1997, Burns 1971); this assumption should be tested in future research. Similarly, the suitability of Model 2 as a predictor of the required number of spawners to maximize smolt production in Statistical Area 3 depends on the recent decadel average smolt production for Zolzap, Lachmach, and Toboggan being an appropriate measure of capacity for those systems.

Both models evaluated in this paper predict the required number of spawners for smolt production. They ignore potential production from ocean-type coho that leave the freshwater environment in their first year. For those Area 3 systems where ocean-type coho contribute to total coho production measured by adult returns, the models would underestimate the required number of spawners to maximize total production. Similarly, to the extent that coho from adjacent streams rear in non-natal streams in the study area, there will be errors in the predicted number of required spawners for those systems. There is very limited data for Statistical Area 3 coho streams to test either of these assumptions.

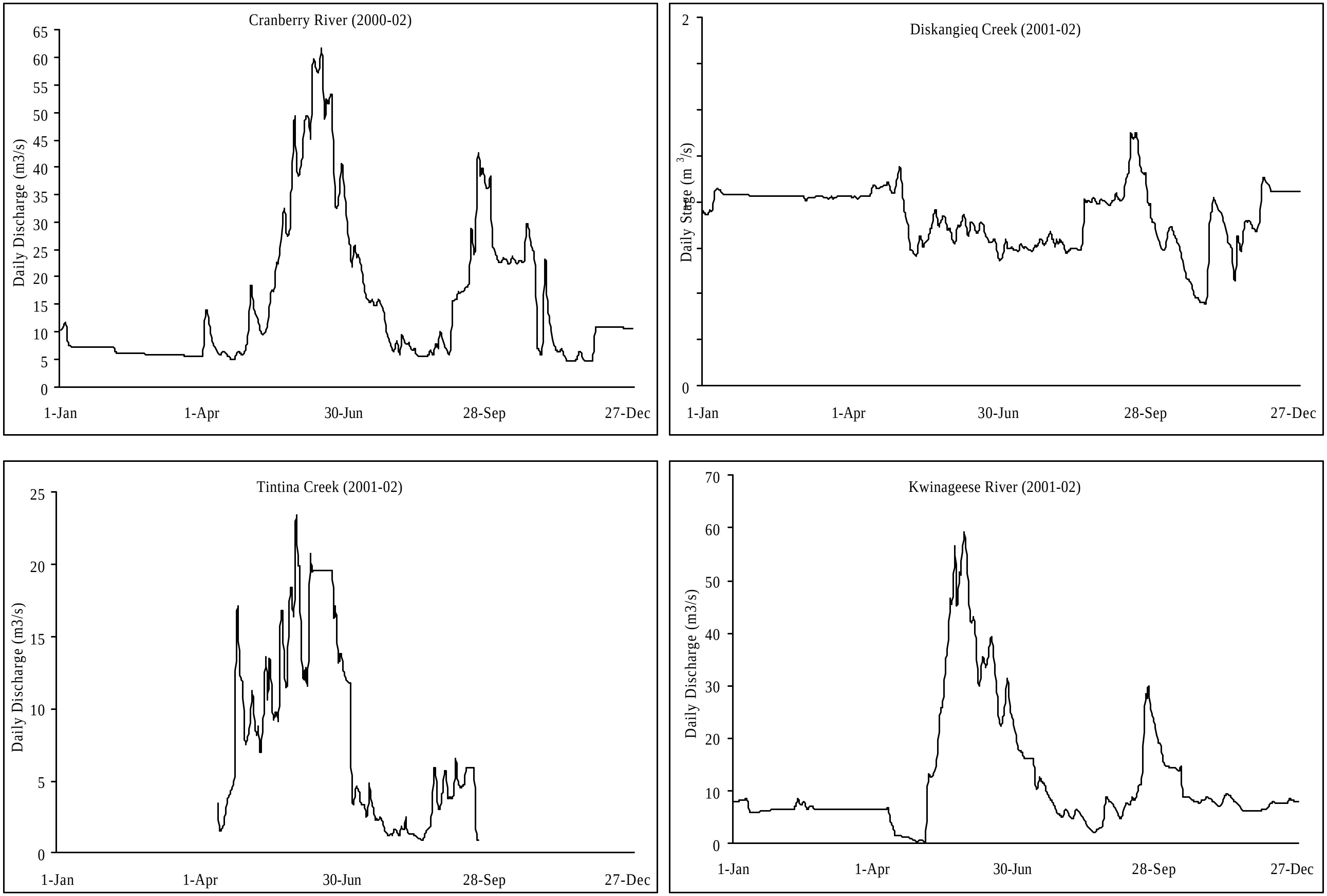

Figure 14. Daily discharge for four Nass River streams.

A number of additional assumptions were made when determining the number of required spawners to maximize smolt production. These include assumptions about freshwater survival, which were shown to have a significant effect on the model predictions. Currently, freshwater survival is only measured at Zolzap Creek. The addition of another coho indicator stock, particularly for the Upper Nass, would greatly enhance understanding of coho production in the Nass region.

Sex ratio was assumed to be one to one. If this is not the case for the majority of streams, then the prediction of the required number of spawners could be biased. Egg retention and other factors potentially limiting spawning success were also not factored into the model. If spawning success is significantly less than 100%, then the required number of spawners would be under predicted. The sensitivity of the model to assumptions about sex ratio, fecundity and spawning success should be evaluated in the future.

Not withstanding the various assumptions and limitations of the models tested, we recommend in the interim that estimates of the required number of spawners for Area 3 coho be based on the results of Model 1 for smolt yield, and that the "average" survival rates from Bradford (1995) be used. There may be considerable error in the predictions for some streams, but on an area basis, the predictions are a major step toward improved fishery management capability for Area 3 coho, especially where escapement goals for coho do not currently exist. The results suggest that appropriate escapement goals should be in the range of 15,000 spawners for Outer Coastal Area 3, 30,000 for the Coastal Nass Area, 26,000 for the Lower Nass Area, and 135,000 for the Upper Nass Area. These spawner abundances would produce, on average, smolt yields in keeping with regional estimates per kilometre for BC and Southeast Alaskan streams.

Comparison to Indicator Stocks

The performance of Model 1 was evaluated against recent average smolt production at Zolzap Creek and Lachmach Creek (data from Baxter and Stephens 2002 and Holtby et al. 1999). A "leave-one-out" analysis of Model 1 was conducted for this evaluation by systematically omitting Zolzap and then Lachmach from the region-wide data set used in the development of Model 1. Table 11 contains the regression parameters used for Model 1 in each case to predict smolt production and spawner requirements for Zolzap and Lachmach.

Table 11. Regression parameters required for Model 1 predictions when Zolzap and Lachmach were excluded from the region-wide dataset.

						Log Length	
Stream Droped	**Adjusted R^2**	**Constant**	**Slope**	**N**	**Resid. Dev.**	**Mean**	**SS Resid.**
None	0.6869	7.87868	0.83923	28	0.71187	1.80268	43.33155
Zolzap	0.6869	7.86990	0.83346	27	0.71830	1.78544	43.10701
Lachmach	0.6835	7.87577	0.83482	27	0.72352	1.77940	42.92216

Smolt production at Zolzap was also compared with age-specific Ricker smolt recruitment models and age-specific Break Point Regression (BPR) or Hockey Stick recruitment model (Neter et al. 1985, Barrowman and Meyers 2000, Bradford et al. 2000). A regression of the form $Y = b_oX$ was used to predict values below the breakpoint, and a second regression of Y = breakpoint was used to predict values above it (i.e., slope = 0). The Hockey Stick model is consistent with the notion that smolt yield reaches a maximum point beyond which additional spawners do not contribute additional smolts. Therefore, the breakpoint of the regression indicates the minimum number of spawners required to seed the habitat.

Model 1, using the "leave-one-out" analysis, smolt predictions were 97% and 64% of the recent decadal averages for Lachmach and Zolzap, respectively (Table 12). However, both model predictions of the required number of spawners were very close to the observed decadal average abundance of spawners at both creeks (1152 vs 984 spawners for Lachmach and 1009 vs 999 spawners for Zolzap). This could be due to the fecundity and/or the freshwater survival values used in the model. As previously illustrated, it is the assumed survival rates used in the model that have the greatest effect on the estimate of the required number of spawners to produce the estimated number of smolts.

The recent (1992-98 broods) MSY for smolt recruitment at Zolzap Creek was estimated at 1,975 spawners and 21,150 smolts using the Ricker stock recruit relation and 967 spawners and 23,577 smolts using the Break Point Regression (Figure 15). The Ricker recruitment function identifies maximum smolt yield beyond which additional spawners cause a reduction in smolt production, whereas, the BPR relation establishes MSY at which point additional spawners do not contribute further to smolt production. A Beverton-Holt relationship would provide similar results with a S_{max} of around 20,000 smolts beyond which additional spawners beyond approximately 2,000

Table 12. Comparison of model results to recent decadel average smolt and spawner abundances and age-specific Ricker and Hockey Stick (Break Point Regression) models at Zolzap and Lachmach creeks.

	Model 1[1]	Model 2	Decadel Average[2]	Ricker MSY[3]	Hockey Stick[3]
Lachmach smolts	26,350	27,091	27,163	Na	Na
Lachmach spawners	1,152	1,203	984	Na	Na
Zolzap smolts	18,977	24,120	29,833	21,150	23,577
Zolzap spawners	1,009	1,286	999	1,975	967

[1] Model 1 derived using "leave-one-out" analysis whereby Zolzap and Lachmach were excluded from region-wide data set when predicting respective smolts production.

[2] Smolt averages are for 1992-2001 smolt years and spawner abundances are for 1992-2000.

[3] Brood year data for stock recruit analyses are from 1992-97 for Zolzap (Baxter and Stephens 2002).

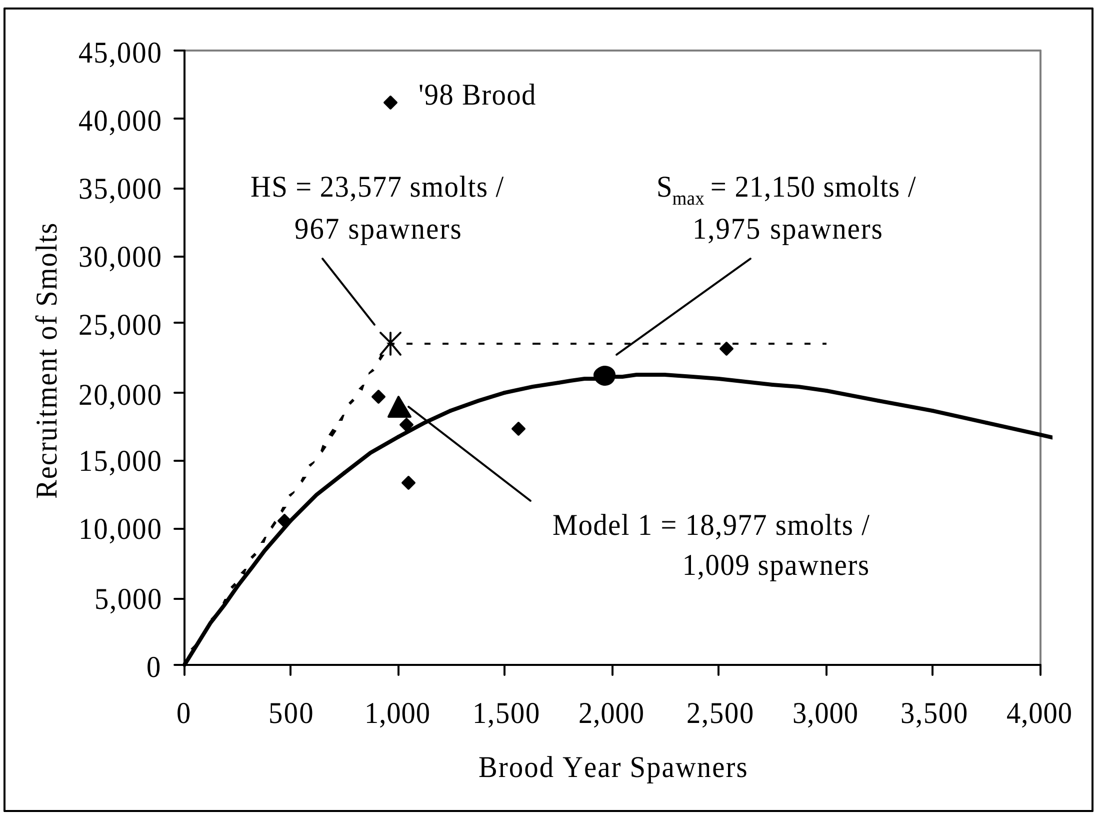

Figure 15. Age-specific Ricker and Hockey Stick recruitment relationships for Zolzap Creek coho smolts, 1992-1998 brood years.

would contribute no further to production. The Lachmach recruitment data were not informative enough to enable a Ricker or Hockey Stick model fit due to the absence of age-specific smolt recruitment information.

Model 1 and the Hockey Stick model predicted very similar required spawner numbers providing some validation to the notion, at least for Zolzap Creek, that the model is predicting the maximum smolt production and the minimum number of coho spawner required, on average.

Both the model estimates of smolt and spawner requirements and the actual estimates for smolt production and spawners at Zolzap and Lachmach are not without error. The actual smolt estimates were derived at these systems (and Toboggan) using smolt fences (e.g. Baxter and Stephens 2002). The decadel smolt estimates for these systems in Table 12 could be in error due to non-natal rearing of coho within and/or outside these parent streams, and errors in counting. For the purpose of comparing model predictions, however, these errors were assumed to be small compared to inter-annual variability in the estimates (see Appendix B). Similarly, errors in spawner estimates were assumed to be small compared to inter-annual variability (SD for Zolzap = 550; SD for Lachmach = 300) as the recent spawner abundance estimates for Lachmach and Zolzap were from weir counts and/or rigorous mark-recapture estimates.

Table 13 compares the model estimates of smolts per spawner with those reported for Zolzap Creek using the Hockey Stick function (this paper), by Bradford et al. (2000) for 14 Washington and southern BC coho streams, and by Shaul et al. (2003) for Southeast Alaskan streams. The habitat model estimates of the required number of spawners are higher than what would be predicted using estimates of smolts per spawner from the other sources, indicating that the survival parameters used in this report may result in an overestimate of the required number of spawners. However, the number of smolts per spawner was similar for the habitat models and for the Zolzap Hockey Stick model indicating that, at least for the lower Nass and coastal areas, the models may be appropriate.

Comparison to Other Area 3 Escapements

Fisheries and Oceans and Nisga'a Lisims Government have been monitoring escapements using area-under-the-curve (AUC) techniques since 2000 for four Area 3 coho streams. As well, coho escapements to Meziadin River have been completely counted at a fishway since 2000. Table 14 compares the habitat model spawner predictions with recent escapement levels for these systems.

Table 13. Comparison of the required number of spawners for maximum smolt production (S_{max}) using various smolts per spawner estimates; Model 1 and 2 (survival estimates), Zolzap Hockey Stick model, Bradford et al. (2000) and Shaul et al. (2003).

	Required Spawners				
	Model 1	Zolzap Hockey Stick	Bradford et al. (2000)	Shaul et al. (2002)	
Smolts per spawner:	19.6	24.5	42.5	30	60
From Model 1 Smolts					
Outside Area 3	15,038	13,855	7,987	11,315	5,657
Coastal Nass	29,794	27,450	15,824	22,417	11,209
Lower Nass	26,854	20,617	11,885	16,837	8,419
Upper Nass	134,609	103,347	59,576	84,400	42,200
Total Area 3	206,296	165,269	95,273	134,969	67,485
	Model 2	Zolzap Hockey Stick	Bradford et al. (2000)	Shaul et al. (2002)	
Smolts per spawner:	19.4	24.5	42.5	30	60
From Model 2 Smolts					
Outside Area 3	15,444	14,191	8,181	11,590	5,795
Coastal Nass	33,344	30,639	17,662	25,022	12,511
Lower Nass	37,319	28,577	16,474	23,338	11,669
Upper Nass	220,273	168,671	97,234	137,748	68,874
Total Area 3	306,380	242,077	139,550	197,696	98,848

Table 14. Comparison of model predictions for spawner abundance with AUC escapement estimates for Statistical Area 3 streams.

AUC System	Model 1	Model 2	2000-02 Range	2000-02 Mean
Salmon Cove	620	565	219-986	573
Diskangieq	1,150	1,475	408-3,325	2,233
Ginlulak	914	1,123	339-1,965	1,180
Ansedegan	474	512	58-1,483	586
Meziadin	9,960	17,069	1,439-5,965	4,149
Upper Nass	134,609	220,273	72,000-168,000	109,000

Both Model 1 and Model 2 spawner predictions were similar to the recent escapement estimates derived for Salmon Cove, Ginlulak, and Ansedegan creeks. The predictions were considerably lower for Diskangieq which could be due to overestimation of escapements or model error. The model-predicted escapements for Meziadin River were significantly higher than the recent escapement estimates (Table 14). Overall, there is greater uncertainty in the habitat model predictions for the Upper Nass River, particularly with respect to the total habitat available to coho, the estimate of the number of smolts per kilometre, and the number of smolts per spawner.

While there is uncertainty with the model estimates of required spawners presented here, there is also uncertainty associated with the actual spawner abundances for Area 3 coho. The Area-Under-The-Curve (AUC) estimates for the Lower Nass and Coastal Nass area streams could have errors in the order of ±50%. As well, there is considerable uncertainty in the Upper Nass Area mark recapture estimates for coho with 95% confidence intervals in the order of 25% to 40% (e.g. Alexander et al. 2002). The Upper Nass estimates are based mark recoveries only at the Meziadin fishway which may bias the estimates (Richard Alexander, LGL Limited, pers. comm.). Mark-recapture estimates of coho returns to the Upper Nass spawning aggregate have ranged from 72,000 to 168,000 since 2000 with a mean of 109,000 (Table 14).

Predicting Total Adult Returns and Harvest Rates

The Area 3 Coho Model can be used to determine harvest rates that result in escapements that maximize smolt production for Area 3 coho assuming various freshwater and marine survivals (Appendix F). Using an average marine survival rate of 10%, the Area 3 Coho Model predicts that a harvest rate of 49% would allow escapement of an adequate number of spawners to achieve S_{max} for Area 3 streams (Table 15).

When marine survival drops to 5.1% or below, the required number of spawners cannot be met at any harvest rate (Table 15). This is consistent with the findings of Bradford et al. (2000). By comparison, smolt-to-adult (marine) survival rates for Zolzap Creek coho have ranged from 2.1% to 8.9% for the 1992-2000 smolt years (Baxter and Stephens 2002). Over the same period, marine survival rates for Lachmach Creek ranged from 5.5% to 17.4% (Joel Sawada, pers. comm.), and for Toboggan Creek coho ranged from 0.05% to 10.4% (Joel Sawada, pers. comm.).

CONCLUSIONS

We conclude that the area aggregate escapement requirements (goals) using Model 1 presented in Table 8 currently represent the best estimates of the number of coho salmon spawners required to produce the maximum smolt yields for Area 3 streams. Additional tests of model assumptions and uncertainty as discussed should be performed in future iterations of model development and refinement. As well, the dataset originally compiled by Bradford et al. (1997) and used to develop Model 1 could perhaps be updated to include more recent years and additional streams to improve the spatial and temporal representativeness of the model. A more critical review of each stream's suitability for input to the model should also be performed. This should include recalculating accessibility to coho for these streams using the Area 3 Coho Production Model algorithm for limiting coho distributions where barriers are not field-verified.

With respect to empirical studies to support the model, we recommend the continuation of escapement estimation for indicator stocks in Area 3 as well as continued mark-recapture estimation of escapement, stock-recruitment analyses, and ground truthing of accessible stream lengths and suitable habitats. Overtime, additional information on known barriers to migration should replace the GIS-based algorithm used to limit coho distribution in Area 3 streams. Information on life-history strategies and population traits for Upper Nass Area coho populations would also aid in determining the appropriateness of the model for these streams. The role of the Nass mainstem in providing additional rearing habitat for Upper Nass Area coho (and perhaps Lower Nass Area coho to some extent) should also be investigated.

Table 15. Required number of spawners and total return for Area 3 coho assuming different marine survival rates.

	Required	Total Return for Various Marine Survivals							
Area	Spawners	2%	4%	5.10%	6%	8%	10%	12%	14%
Outer Coastal Area 3	15,038	6,789	13,578	17,312	20,366	27,155	33,944	40,733	47,522
Coastal Nass Area	29,794	13,450	26,901	34,298	40,351	53,801	67,252	80,702	94,152
Lower Nass Area	26,854	10,102	20,205	25,761	30,307	40,410	50,512	60,615	70,717
Upper Nass Area	134,609	50,640	101,280	129,132	151,920	202,560	253,200	303,840	354,480
Total	206,296	80,982	161,963	206,503	242,945	323,927	404,908	485,890	566,872
Percent of Required Spawners		39%	79%	100%	118%	157%	196%	236%	275%
Allowable Harvest Rate				0%	15%	36%	49%	58%	64%

[1] Harvest rate that would result in escapements that maximize smolt production

LITERATURE CITED

Alaska Department of Fish and Game (ADF&G). 2001. Alaska's conservation mandate. http://www.state.ak.us/adfg/geninfo/hot/brochure.htm (Sept. 2001).

Alexander, R.F., M.R. Link, and R.C. Bocking. 2002. The 2000 fishwheel project on the Nass River, BC. Can. Manuscr. Rep. Fish. Aquat. Sci. 2626: 118 p.

Baranski, C. 1989. Coho smolt production in ten Puget Sound streams. Wash. Dep. Fish. Tech. Rep. 99: 29 p.

Barrowman, N.J. and R.A. Myers. 2000. Still more spawner-recruitment curves: the hockey stick and its generalizations. Can. J. Fish. Aquat. Sci. 57: 665-676.

Baxter, B.E. 2003. Adult and juvenile coho salmon enumeration and coded-wire tag recovery analysis for Zolzap Creek, BC. 2002. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2646: vii + 44 p.

Baxter, B.E. and C.Y. Stephens. 2002. Adult and juvenile coho salmon enumeration and coded-wire tag recovery analysis for Zolzap Creek, BC. 2001. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2601: viii + 44 p.

Baxter, B.E. and C.Y. Stephens. 2002a. Adult and juvenile coho salmon enumeration and coded-wire tag recovery analysis for Zolzap Creek, BC. 2000. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2598: viii + 44 p.

Baxter, B.E. and C.Y. Stephens. 2002b. Adult and juvenile coho salmon enumeration and coded-wire tag recovery analysis for Zolzap Creek, BC. 1999. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2597: viii + 44 p.

Baxter, B.E., C.Y. Stephens and B.L. Nass. 2001. Adult and juvenile coho salmon enumeration and coded-wire tag recovery analysis for Zolzap Creek, BC. 1998. Can. Manuscr. Rep. Fish. Aquat. Sci. No. 2566: viii + 44 p.

Baxter, B.E., C.Y. Stephens, and R.C. Bocking. 2002. Nisga'a catch monitoring program: 2001 Nisga'a fishery. Nisga'a Fisheries Report No. NF01-04.

Bilby, R.E. and P.A. Bisson. 1987. Emigration and production of hatchery coho salmon (*Oncorhynchus kisutch*) stocked in streams draining an old-growth and a clear-cut watershed. Can. J. Fish. Aquat. Sci. 44: 1397-1407.

Bisson, P.A., R.A. Nielsen, R.A. Palmason, and L.E. Gore. 1982. A system of naming habitat types in small streams with examples of habitat utilization by salmonids during low stream flow. In Acquisition and utilization of aquatic habitat information. Edited by N.A. Armatrout. American Fisheries Society, Bethesda, MD. Pp. 62-73.

Bjorn, T.C. and D.W. Reiser. 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication 19: 83-138.

Bocking, R.C., C.K. Parken, and D.Y. Atagi. 2001. Nass River steelhead habitat capability production model and preliminary escapement goals. Unpublished report for Ministry of Water, Land and Air Protection, Smithers, British Columbia.

Bradford, M.J. 1995. Comparative review of Pacific salmon survival rates. Can. J. Fish. Aquat. Sci. 52: 1327-1338.

Bradford, M.J., G.C. Taylor and J.A. Allan. 1997. Empirical review of coho salmon smolt abundance and the prediction of smolt production at the regional level. Trans. Am. Fish. Soc. 126: 49-64.

Bradford, M.J., R.A. Myers and J.R. Irvine. 2000. Reference points for coho salmon (*Oncorhynchus kisutch*) harvest rates and escapement goals based on freshwater production. Can. J. Fish. Aquat. Sci. 57: 677-686.

Brown, T.G. and G.F. Hartman. 1988. Contribution of seasonally flooded lands and minor tributaries to coho (*Oncorhynchus kisutch*) salmon smolt production in Carnation Creek, a small coastal stream in British Columbia. Trans. Am. Fish. Soc. 1217: 546-551.

Brown, T.G., L. Barton, and G. Langford. 1996. The use of a geographic information system to evaluate terrain resource information management (TRIM) maps and to measure land use patterns for Black Creek, Vancouver Island. Can. Manuscr. Rep. Fish. Aquat. Sci. 2395: 34 p.

Brown, T.G., L. Barton, and G. Langford. 1999. Coho salmon habitat within Black Creek, Vancouver Island. Can. Tech. Rep. Fish. Aquat. Sci. 2294: 75 p.

Burns, J.W. 1971. The carrying capacity for juvenile salmonids in some northern California streams. Calif. Fish and Game. Vol. 57 (1) : 44-57.

Cederholm, C.J. and L.M. Reid. 1987. Impacts of forest management on coho salmon (*Oncorhynchus kisutch*) populations of the Clearwater River, Washington: project summary, p. 373-398. In E.W. Salo and T.W. Cundy (ed.). Streamside Management: forestry and fisheries interactions. Contribution 57, College of Forest Resources, University of Washington, Seattle, WA.

Cederholm, C.J. and W.J. Scarlett. 1991. The beaded channel: a low-cost technique for enhancing winter habitat of coho salmon. Amer. Fish. Soc. Symposium 10: 104-108.

Cederholm, C.J., M.D. Kunze, T. Murota, and A Sibatani. 2000. Pacific salmon carcasses: essential contributions of nutrients and energy for aquatic and terrestrial ecosystems. Fisheries 24, No. 10: 6-15.

Chapman, D.W. 1965. Net production of juvenile coho salmon in three Oregon streams. Trans. Am. Fish. Soc. 94 (1): 40-52.

Crone, R.A. and C.E. Bond. 1976. Life history of coho salmon, *Oncorhynchus kisutch*, in Sashin Creek, southeastern Alaska. Fish. Bull. U.S. 74: 897-923.

DFO. 1991. Stream Summary Catalogue Subdistrict #3. Fish Habitat Inventory and Information Program. North Coast Division, Fisheries Branch, Department of Fisheries and Oceans.

Draper, N.R., and W. Smith. 1981. Applied Regression Analysis (Second Ed.). John Wiley and Sons. 709p

Faush, K.D., C.L. Hawkes, and M.G. Parsons. 1988. Models that predict standing crop of stream fish from habitat variables: 1950-85. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-213, Portland, OR. 52 p.

Fisheries and Oceans Canada. 1998. Draft Wild Salmon Policy. A new direction for Canada's Pacific Salmon Fisheries, policy paper, released for review October 1998. http://www-comm.pac.dfo-mpo.gc.ca/english/newdirections/default.htm (Sept. 2001).

FISS. 1991a. Fish Habitat Inventory and Information Program Stream Summary Catalogue: Subdistrict #3A, Lower Nass. Department of Fisheries and Oceans.

FISS. 1991b. Fish Habitat Inventory and Information Program Stream Summary Catalogue: Subdistrict #3B, Upper Nass. Department of Fisheries and Oceans.

Hancock, M.J. and D.E. Marshall. 1984. Catalogue of salmon streams and spawning escapements of Statistical Area 3 (Nass River) including adjacent streams. Can. Data Rep. Fish. Aquat. Sci. No. 429. 371 p.

Hartman, G.F., B.C. Andersen, and J.C. Scrivener. 1981. Seaward movement of coho salmon (O*ncorhynchus kisutch*) fry in Carnation Creek, an unstable coastal stream in British Columbia. Can. J. Fish. Aquat. Sci. 39:588-597.

Holtby, L.B. and J.C. Scrivener. 1989. Observed and simulated effects of climatic variability, clear-cut logging, and fishing on the numbers of chum salmon (*Oncorhyhnchus keta*) and coho salmon (*O. kisutch*) returning to Carnation Creek, British Columbia, p. 62-81. In C.D. Levings, L.B. Holtby, and M.A. Henderson [ed.] Proceedings of the National Workshop of Effects of Habitat Alteration on Salmonid Stocks. Can. Spec. Publ. Fish. Aquat. Sci. 105.

Holtby, L.B., B.C. Andersen, and R.K. Kadowaki. 1990. Importance of smolt size and early ocean growth to interannual variability in marine survival of coho salmon (O*ncorhynchus kisutch*). Can. J. Fish. Aquat. Sci. 47: 2181-2194.

Holtby, B., B. Finnegan, D. Chen, and D. Peacock. 1999. Biological Assessment of Skeena River coho salmon. Canadian Stock Assessment Secretariat Research document 99/140.

Horton, R. E. 1945. "Erosional Development of Streams and Their Drainage Basins: Hydrophysical Approach to Quantitative Morphology." Bull. Geol. Soc. of America, Vol 56, pp 275-370.

Irvine, J.R. and N.T. Johnston. 1992. Coho salmon (*Oncoryhnchus kisutch)* use of lakes and streams in the Keogh River drainage, British Columbia. Northwest Sci. 66: 15-25.

Johnson, N.L., and S. Kotz. 1970. Distributions in Statistic: Continuous Univariate Distributions, Vol 1. John Wiley and Sons, New York. 300p.

Jowett, I.G. 1992. River hydraulics and instream habitat modelling for river biota. In: Mosley, M.P. (Ed.), Waters of New Zealand, Wellington, New Zealand Hydrological Society, 249-263.

Knight, N.J. 1980. Factors affecting smolt yield of coho salmon (*Oncoryhnchus kisutch*) in three Oregon streams. M.Sc. thesis, Oregon State University, Corvallis, Oreg.

Lister, D.B. 1968. Use of inaccessible stream areas for coho salmon production. Fish. Mar. Ser. MS Rep. On File No. 32-5-45: 9 p.

Marshall, D.E. and E.W. Britton. 1990. Carrying capacity of coho salmon streams. Can. Man. Rep. Fish Aquat. Sci. 2058: 32 p.

Mason, J.C. 1974. A further appraisal of the response to supplemental feeding of juvenile coho (*O. kisutch*) in an experimental stream. Fish. Mar. Ser. Tech. Rep. 470: 25 p.

Mason, J.C. 1975. Seaward movement of juvenile fishes, including lunar periodicity in the movement of coho salmon (*Oncoryhnchus kisutch*) fry. J. Fish. Res. Board Can. 32: 2542-2547.

Mason, J.C. and D.W. Chapman. 1965. Significance of early emergence, environmental rearing capacity and behavioural ecology of juvenile coho salmon in stream channels. J. Fish. Res. Bd. Can. 22: 175-190.

Meidinger, D. and J. Pojar. 1991. Ecosystems of British Columbia. Special report series, ISSN 0843-6452 ; No. 6. British Columbia Ministry of Forests. Victoria, BC.

Milliken, G.A. and D.E. Johnson. 2002. Analysis of Messy Data, Volume III: Analysis of Covariance. Chapman and Hall/CRC, New York. 605p.

MOE. 1977. Aquatic Biophysical Maps. Resources Analysis Branch. Ministry of the Environment. Victoria, B.C.

Neter, J., W. Wasserman, and M. H. Kutner. 1985. Applied linear statistical models: regression, analysis of variance, and experimental designs. Irwin, Homewood, IL.

Nickelson, T.E. 1998. A habitat-based assessment of coho salmon production potential and spawner escapement needs for Oregon coastal streams. Information Reports Number 98-4. Oregon Department of Fish and Wildlife. Portland Oregon.

Nickelson, T.E., J.D. Rodgers, S.L. Johnson, and M. Solazzi. 1992. Seasonal changes in habitat use by juvenile coho salmon (*Oncorhynchus kisutch*) in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 49: 783-789.

NTC. 1994-98. Watershed Restoration Program reports submitted to Ministry of Environment, Lands and Parks. Smithers, BC.

NTC. 1998a. Fish and fish habitat inventory of Kincolith watershed, 1996-97. Report prepared by LGL Limited and the Nisga'a Tribal Council for Ministry of Environment, Lands and Parks. Smithers, BC.

NTC. 1998b. Fish and fish habitat inventory of Burton and Monkley watersheds, 1997. Report prepared by LGL Limited and the Nisga'a Tribal Council for Ministry of Environment, Lands and Parks. Smithers, BC.

NTC. 1998c. Fish and fish habitat inventory of Greenville and Diskangieq watersheds, 1997. Report prepared by LGL Limited and the Nisga'a Tribal Council for Ministry of Environment, Lands and Parks. Smithers, BC.

NTC. 1998d. Fish and fish habitat inventory of Gish, Chemainuk and Grease watersheds, 1997. Report prepared by LGL Limited and the Nisga'a Tribal Council for Ministry of Environment, Lands and Parks. Smithers, BC.

NTC. 1998e. Fish and fish habitat inventory of Tseax and Vetter watersheds, 1997. Report prepared by LGL Limited and the Nisga'a Tribal Council for Ministry of Environment, Lands and Parks. Smithers, BC.

NTC. 1998f. Fish and fish habitat inventory of Ksemamaith, Kwiniak, Ansedegan, Kwinyarh, and Ginlulak watersheds, 1997. Report prepared by LGL Limited and the Nisga'a Tribal Council for Ministry of Environment, Lands and Parks. Smithers, BC.

NTC. 1998g. Fish and fish habitat inventory of Iknouk and Keaszoah watersheds, 1997. Report prepared by LGL Limited and the Nisga'a Tribal Council for Ministry of Environment, Lands and Parks. Smithers, BC.

NTC. 1998h. Fish and fish habitat inventory of Cugiladap, Wegiladap, Giswatz, Wilyayaanooth, Inieth and Gingietl watersheds, 1997. Report prepared by LGL Limited and the Nisga'a Tribal Council for Ministry of Environment, Lands and Parks. Smithers, BC.

ODFW. 1992. Oregon's Wild Fish Management Policy. http://www.dfw.state.or.us/ODFWhtml/InfoCntrFish/PDFs/BKGWildFish.pdf (Sept. 2001).

Pess, G.R., D.R. Montgomery, E.A. Steel, R.E. Bilby, B.E. Feist, and H.M. Greenberg. 2002. Landscape characteristics, land use, and coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Wash., U.S.A. Can. J. Fish. Aquat. Sci. 59: 613-623.

Powers, P.D. and J. F. Orsborn. 1985. Analysis of barriers to upstream fish migration: an investigation of the physical and biological conditions affecting fish passage success at culverts and waterfalls. U.S. Department of Energy, Bonneville Power Administration. Project 82-14 Final Report. Portland, OR.

Ptolemy, R.A., M. Ramsey, and D. Sollitt. 2004. Results of steelhead stock monitoring (1988-2004) in the Bella Coola River and implications for population recovery. Prepared for Ministry of Water, Land and Air Protection, Fish and Wildlife Science and Allocation, Victoria, BC.

Reeves, G.H., F.H. Everest, and T.E. Nickelson. 1989. Identification of physical habitats limiting the production of coho salmon in western Oregon and Washington. U.S. Forest Service General Technical Report PNW-245.

Rosenfeld, J., M. Porter and E. Parkinson. 2000. Habitat factors affecting the abundance and distribution of juvenile cutthroat trout (*Oncorhynchus clarki*) and coho salmon (*Oncoryhnchus kisutch*). Can. J. Fish. Aquat. Sci. 57: 766-774.

Saimoto, R.K. and R.S. Saimoto. 1998. Reconnaissance level stream inventory of the Bell-Irving/Bowser watershed. Prepared by SKR Consultants for Ministry of Environment, Lands and Parks, Smithers, BC.

Salo, E.O. and W.H. Bayliff. 1958. Artificial and natural production of silver salmon (*Oncorhynchus kisutch*) at Minter Creek, Washington. Wash. Dept. Fish. Res. Bull. No. 4: 76 p.

Sharma, R. and R. Hilborn. 2001. Empirical relationships between watershed characteristics and coho salmon (*Oncorhynchus kisutch*) smolt abundance in 14 western Washington streams. Can. J. Fish. Aquat. Sci. 58: 1453-1463.

Shaul, L., S. McPherson, E. Jones, and K. Crabtree. 2003. Stock status and escapement goals for coho salmon stocks in Southeast Alaska. Special Publication No. 03-02. Alaska Department of Fish and Game.

Slaney, T.L., K.D. Hyatt, T.G. Northcote, and R.J. Fielden, 1996. Status of Anadromous Salmon and Trout in British Columbia and Yukon. Fisheries, 21(10):20–35.

Solazzi, M.F., T.E. Nickelson, S.L. Johnson, and J.D. Rodgers. 2000. Effects of increasing winter rearing habitat on abundance of salmonids in two coastal Oregon streams. Can. J. Fish. Aquat. Sci. 57: 906–914.

Strahler, A.N. 1957. Quantitative analysis of watershed geomorphology. Trans. Am. Geophys. Union 38: 913-920.

Stuart, T. A. 1962. The leaping behaviour of salmon and trout at falls and obstructions. Department of Agriculture and Fisheries for Scotland, Freshwater and Salmon Fisheries Research Report 28, Edinburgh.

Tschaplinski, P.J. 1987. The use of estuaries as rearing habitats by juvenile coho salmon. *In* Proceedings of a Workshop: Applying 15 Years of Carnation Creek Results. *Edited by* T.W. Chamberlin. Carnation Creek Steering Committee, Nanaimo, B.C. pp. 123-142.

Van Schubert, R.M. 1999. 1:20,000 reconnaissance fish and fish habitat inventory of the Taylor and Upper Nass River watersheds. Prepared by EDI Environmental Dynamics Inc. for Ministry of Environment, Lands and Parks, Smithers, BC.

WDFW. 1997. Policy of Washington Department of Fish and Wildlife and Western Washington Treaty Tribes Concerning Wild Salmonids. http://www.wa.gov:80/wdfw/faq/wspfaq.htm (Sept. 2001).

APPENDICES

Appendix A Watershed area, Mean Annual Discharge (MAD), stream order and accessible length for Area 3 coho salmon streams.

	Watershed	Area (km^2)	MAD (m^3/s)	Stream Order	Minimum Stream Order	Accessible length1 (<8% gradient) (m)	Accessible length1 (<6% gradient) (m)	Accessible length1 (<4% gradient) (m)	Accessible length1 (<2% gradient) (m)
Outside Area 3			*stream order parameter B =*		*2*				
1	American Bay Creek	2.6	0.3	3	3	790	740	690	410
2	Bill Creek	12.6	1.5	3	3	3340	3290	3190	2970
3	Boat Harbour Creek	2.7	0.3	3	3	1070	1070	840	610
4	Brundige Creek	11.4	1.3	3	3	4840	4840	4780	4170
5	Crow Lagoon Creek	18.6	2.2	4	3	1020	960	800	570
6	Ensheshese River	63.0	7.4	5	3	19460	18670	17530	15680
7	Fortune Creek	16.0	1.9	4	3	5670	5530	4820	4080
8	Khutzeymateen River	370.8	43.8	7	5	30740	30190	29420	28550
9	Lachmach River	41.6	4.9	4	3	11370	11310	10760	9740
10	Leverson Creek	24.0	2.8	4	3	6750	6440	6100	5590
11	Manzanita Cove Creek	10.5	1.2	2	2	5840	5330	4820	3880
12	Marion Creek	13.6	1.6	3	3	3740	3080	2680	2180
13	Sandy Bay Creek	11.6	1.4	5	3	7820	7280	6360	4410
14	Stumaun Creek	15.7	1.9	4	3	7310	6380	5050	3860
15	Toon River	131.9	15.6	5	3	21180	19850	18250	14360
16	Tracy Creek	7.7	0.9	3	3	1330	1330	1330	1300
17	Tsampanaknok Bay Creek	10.2	1.2	4	3	1390	1290	1080	630
18	Whitley Point Creek	15.8	1.9	4	3	12260	11660	11080	10290
	Subtotal					**145920**	**139240**	**129580**	**113280**

Appendix A (cont).

	Watershed	Area (km^2)	MAD (m^3/s)	Stream Order	Minimum Stream Order	Accessible length1 (<8% gradient) (m)	Accessible length1 (<6% gradient) (m)	Accessible length1 (<4% gradient) (m)	Accessible length1 (<2% gradient) (m)
Coastal Nass Area			*stream order parameter B =*		*2*				
19	Bear River	710.5	40.0	7	5	63800	62800	61780	60170
20	Bell Bay Creek	31.6	1.8	5	3	8220	5620	3950	2230
21	Bonanza Creek	31.2	1.8	4	3	5760	5270	4430	3080
22	Cascade Creek	19.6	1.1	4	3	1380	1260	1090	710
23	Chambers Creek	89.9	10.6	4	3	10010	9330	8920	8090
24	Dogfish Bay Creek	21.9	1.2	4	3	7550	6890	6180	5110
25	Donahue Creek	70.8	4.0	5	3	14610	10440	6990	4480
26	Georgie River	160.4	9.0	6	4	29030	25780	20410	12170
27	Illiance River	91.6	5.2	5	3	1560	1550	1480	1480
28	Isaac Creek	14.2	0.8	3	3	2840	2790	2520	2410
29	Kincolith River	225.9	12.7	4	3	30180	29390	28680	27180
30	Kitsault River	258.6	14.6	9	7	25850	25690	25640	25370
31	Kshwan River	175.4	9.9	8	6	18780	18560	18210	16960
32	Kwinamass River	284.0	33.6	6	4	38880	37670	35680	31290
33	Lime Creek	27.9	1.6	4	3	2230	1780	1400	780
34	Lizard Creek	32.2	3.8	4	3	2650	2650	2500	2280
35	Olh Creek	71.6	4.0	5	3	1950	1950	1950	1950
36	Pearce Island No1	17.2	1.0	3	3	2990	2940	2940	2740
37	Roberson Creek	8.0	0.5	3	3	850	690	530	310
38	Rodgers Creek	14.2	0.8	4	3	6060	5740	4890	3600
39	Roundy Creek	16.2	0.9	3	3	1830	1320	940	550
40	Salmon Cove Creek	24.9	1.4	4	3	5340	5160	4860	3730
41	Scowbank Creek	26.3	1.5	3	3	1320	860	550	330
42	Stagoo Creek	78.0	4.4	5	3	27610	26540	24820	21850
43	Tauw Creek	9.4	0.5	3	3	240	180	130	80
44	Wilauks Creek	11.3	0.6	4	3	3520	3410	3350	3090
	Subtotal					**315040**	**296260**	**274820**	**242020**

Appendix A (cont).

	Watershed	Area (km^2)	MAD (m^3/s)	Stream Order	Minimum Stream Order	Accessible length1 (<8% gradient) (m)	Accessible length1 (<6% gradient) (m)	Accessible length1 (<4% gradient) (m)	Accessible length1 (<2% gradient) (m)
Lower Nass River				*stream order parameter B =*	*2*				
45	Anliyen Creek (Greenville)	40.7	2.6	4	3	7910	7260	6880	5530
46	Ansedagan Creek	28.5	1.8	4	3	3110	2920	2720	2280
47	Anudol Creek	123.7	7.8	5	3	6410	6380	6380	5950
48	Burton Creek	96.0	11.5	5	3	280	280	220	220
49	Chemainuk Creek	58.1	6.9	4	3	15050	14670	13760	11200
50	Cugiladap Creek	6.2	0.4	3	3	1290	1220	980	500
51	Disangieq Creek	36.4	2.3	4	3	8960	8580	8160	6410
52	Gingietl Creek	14.7	0.9	3	3	1370	920	720	270
53	Ginlulak Creek	43.3	2.7	4	3	6820	6700	5840	5320
54	Gish Creek	14.7	0.9	3	3	7200	6580	5410	3830
55	Giswatz Creek	13.3	0.8	3	3	1670	1440	1190	470
56	Gitwinksihlkw Creek	7.0	0.4	3	3	1070	1000	780	610
57	Iknouk River	112.4	7.1	4	3	25800	24740	23780	21260
58	Inieth Creek	9.5	0.6	3	3	760	710	480	300
59	Ishkeenickh River	579.4	36.6	7	5	70070	68310	64020	53440
60	Keazoah Creek	11.5	0.7	3	3	770	770	650	470
61	Ksemamaith River	68.4	4.3	4	3	2030	2030	1840	1410
62	Kwiniak Creek	248.1	15.7	5	3	11460	10980	10460	9230
63	Kwinyarh Creek	15.6	1.0	3	3	1520	1340	1020	720
64	Monkley Creek	35.7	4.3	4	3	7590	6320	4930	3220
65	Quilgauw Creek	37.0	2.3	4	3	9600	9500	9300	8870
66	Seaskinnish Creek	204.6	12.9	5	3	8710	8530	8390	7580
67	Tseax River	608.3	38.4	6	4	16770	16530	16020	13370
68	Wegiladap Creek	17.0	1.1	4	3	1190	1010	770	590
69	Welda Creek	31.3	3.7	3	3	710	610	560	250
70	Wilyayaanooth Creek	12.7	0.8	3	3	770	690	570	510
71	Zolzap Creek	32.0	2.0	5	3	7810	7630	7280	6880
	Subtotal					**226700**	**217650**	**203110**	**170690**

Appendix A (cont).

	Watershed	Area (km^2)	MAD (m^3/s)	Stream Order	Minimum Stream Order	Accessible length1 (<8% gradient) (m)	Accessible length1 (<6% gradient) (m)	Accessible length1 (<4% gradient) (m)	Accessible length1 (<2% gradient) (m)
Upper Nass River				*stream order parameter B =*	*2*				
72	Bell-Irving River -Above Teigen	1223.5	83.1	7	5	121590	118880	114320	107860
73	Bell-Irving River -Bowser to Teigen	687.8	46.7	7	5	86790	85160	81910	77900
74	Bell-Irving River -below Bowser	456.1	31.0	7	5	43720	43490	42060	39070
75	Bowser River	1262.0	85.7	7	5	92800	92450	91330	88520
76	Cranberry River	974.8	41.2	7	5	143870	141750	136590	125480
77	Damdochax Creek	737.4	50.1	7	5	62450	62250	61460	57730
78	Hodder Creek	72.3	4.9	5	3	21350	19180	15450	6880
79	Kinskuch River	476.9	32.4	5	3	20	20	20	20
80	Kiteen River	885.5	37.4	7	5	72480	71080	67950	62540
81	Konigus Creek	471.7	32.0	6	4				
82	Kotsinta Creek	312.4	21.2	5	3	26210	22290	18220	14900
83	Kshadin Creek	105.1	6.6	5	3	70	70	20	20
84	Kwinageese River	552.3	37.5	6	4	152100	143640	129230	112520
85	Kwinatahl River	306.1	19.3	6	4	8610	8550	8380	7980
86	Meziadin River	735.6	48.9	6	4	110730	104380	93210	78010
87	Muskaboo Creek	614.9	41.8	6	4				
88	Panorama Creek	90.6	6.2	5	3				
89	Paw Creek	176.7	12.0	6	4	43090	41540	37640	32340

Appendix A (cont).

	Watershed	Area (km^2)	MAD (m^3/s)	Stream Order	Minimum Stream Order	Accessible length1 (<8% gradient) (m)	Accessible length1 (<6% gradient) (m)	Accessible length1 (<4% gradient) (m)	Accessible length1 (<2% gradient) (m)
Upper Nass River (cont)			*stream order parameter B =*		*2*				
90	Saladamis Creek	75.0	5.1	5	3	17560	15440	11090	6800
91	Sallysout Creek	333.2	22.6	6	4	1670	1670	1370	1120
92	Sanskisoot Creek	103.3	7.0	5	3	30070	23660	16340	11490
93	Sanyam Creek	96.6	6.6	5	3	340	300	260	150
94	Shumal Creek	99.6	6.3	4	3	16360	15610	14560	9680
95	Taft Creek	474.0	32.2	6	4	50000	45030	38040	30370
96	Taylor River	753.2	51.2	7	5				
97	Tchitin River	248.2	16.9	6	4	16990	16940	16820	16120
98	Teigen Creek	351.7	23.9	6	4	64090	60480	53750	43810
99	Treaty Creek	427.1	29.0	6	4	51920	49380	46390	43860
100	Upper Nass River	735.6	50.0	6	4				
101	Vile Creek	188.0	12.8	5	3	49490	40590	31760	23140
102	White River	954.0	64.8	6	4	144600	141970	135020	123070
	Subtotal					**1802920**	**1705560**	**1556900**	**1360220**

Appendix B Mean annual yield of coho smolts and accessible stream length data from Bradford et al. (1997).

Stream/Side Channel	Latitude	Geographic Region	Years of Data	Accessible Length (km)	Mean Smolt Yield	SD	CV	Yield per km
Porcupine Creek	56 11	SEAK	4	5.2	4,694	915	0.19	903
Sashin Creek	55 23	SEAK	10	1.1	1,654	621	0.38	1,504
Berners River		SEAK	11	55.7	196,283			3,524
Auke Creek		SEAK	21	1.9	6,727			3,541
Hugh Smith Lake		SEAK	17	4.0	32,036			8,009
Toboggan[2]		NBC	10	17.5	50,724	23,595	0.47	2,892
Zolzap Creek[3]	55 15	NBC	9	9.7	29,833	15,452	0.52	3,088
Lachmach River[1]	54 17	NBC	10	11.4	27,163	12,942	0.48	2,383
Hooknose Creek	52 08	NBC	10	5.8	4,987	1,618	0.32	855
Keogh River	50 40	SBC	11	21.8	71,062	15,706	0.22	3,260
Quinsam River	49 59	SBC	5	54.9	42,388	9,353	0.22	772
Tenderfoot Creek	49 55	SBC	3	0.6	7,923	2,546	0.32	12,989
Black Creek	49 52	SBC	10	33.0	59,065	24,314	0.41	1,790
Meighn Creek	49 45	SBC	3	3.2	5,634	2,917	0.52	1,761
Trent River	49 38	SBC	6	7.9	16,255	5,210	0.32	2,052
Chef Creek	49 27	SBC	3	4.3	14,708	3,305	0.22	3,420
Nile Creek	49 25	SBC	9	6.0	4,973	1,381	0.28	823
Hunt's Creek	49 23	SBC	12	5.4	5,110	2,086	0.41	946
Qualicum River	49 23	SBC	15	11.2	34,807	14,659	0.42	3,122
French Creek	49 21	SBC	5	22.1	29,471	10,364	0.35	1,334
Salmon River	49 08	SBC	7	31.3	29,369	11,927	0.41	939
Coghlan Creek	49 07	SBC	7	5.1	11,787	3,222	0.27	2,334
Hopedale Creek	49 06	SBC	3	2.5	7,554	3,590	0.48	3,034
Rust Creek	49 06	SBC	3	0.3	1,295	690	0.53	4,317
Ryder Creek	49 06	SBC	3	4.1	3,590	1,923	0.54	867
Street Creek	49 06	SBC	3	1.6	1,479	326	0.22	924
Salwein Creek	49 06	SBC	4	6.0	8,955	3,169	0.35	1,493
Carnation Creek	48 56	SBC	20	3.1	2,996	905	0.30	966
Little Pilchuck Creek	47 59	WA	13	9.7	28,307	7,069	0.25	2,906
South Fork Skykomish R	47 50	WA	5	92.4	208,758	29,278	0.14	2,259
Lost Creek	47 39	WA	9	3.4	2,355	1,278	0.54	697
Wildcat Creek	47 39	WA	9	6.7	3,873	1,553	0.40	576
Christmas Creek	47 39	WA	10	9.3	1,110	762	0.69	119
Big Beef Creek	47 39	WA	12	16.4	30,072	9,530	0.32	1,834
Snahapish Creek	47 39	WA	13	19.2	8,038	3,274	0.41	419
Shale Creek	47 38	WA	11	7.9	3,000	1,439	0.48	380
Hurst Creek	47 34	WA	12	7.8	5,050	5,050	1.00	647
Clearwater River	47 33	WA	4	151.7	67,971	16,769	0.25	448
Bear Creek	47 29	WA	10	2.4	552	233	0.42	234
Courtney Creek	47 28	WA	10	3.6	1,156	369	0.32	324
Little Tahuya Creek	47 27	WA	10	1.4	7,208	3,266	0.45	5,186
Mission Creek	47 26	WA	7	15.2	14,307	5,048	0.35	944

Appendix B (cont).

Stream/Side Channel	Latitude	Geographic Region	Years of Data	Accessible Length (km)	Mean Smolt Yield	SD	CV	Yield per km
Minter Creek	47 22	WA	11	16.7	28,456	7,337	0.26	1,704
Harris Creek	47 21	WA	9	11.6	25,772	7,718	0.30	2,220
Mill Creek	47 12	WA	12	16.5	24,809	7,997	0.32	1,503
Deschutes River	46 57	WA	6	54.0	64,675	25,825	0.40	1,198
Gnat Creek	46 12	OR	5	4.8	2,048	1,041	0.51	427
Spring Creek	45 37	OR	10	0.5	1,360	583	0.43	2,894
Sand Creek	45 17	OR	3	9.7	1,207	133	0.11	124
Fish Creek	45 09	OR	3	16.7	2,689	373	0.14	161
Deer Creek	44 32	OR	15	2.3	2,014	617	0.31	868
Flynn Creek	44 31	OR	14	1.4	667	366	0.55	466
Needle Branch Creek	44 31	OR	14	1.0	283	138	0.49	292
Waddell Creek	37 06	CA	4	10.3	6,445	4,266	0.66	626
SEAK Mean			12.6	13.6			0.29	3,496
NBC Mean			9.8	11.1			0.45	2,305
SBC Mean			6.9	11.8			0.36	2,481
BC Mean			7.4	11.7			0.37	2,451
WA Mean			9.6	24.8			0.41	1,311
OR Mean			9.1	5.2			0.36	747
Overall Mean			8.8	15.4			0.39	1,913

[1] Lachmach mean for smolt years 1991-2000 (Joel Sawada, pers. comm.).

[2] Toboggan Creek mean for smolt years 1991-2000 (Joel Sawada, pers. comm.).

[3] Zolzap Creek mean for smolt years 1992-2000 (Baxter et al. 2001)

[4] Hunts Creek Length modified according to Myers

Appendix C Smolt yield estimates for Area 3 coho streams using 2 different models.

					Total Smolts			
	Watershed	Area (km^2)	Stream Order	Stream Length (m)	Model 1		Model 2	
Outside Area 3		Beta=	*2*	G8	Estimate	St. Dev.	Estimate	St. Dev.
1	American Bay Creek	2.6	3	790	2,886	2,540	1,882	897
2	Bill Creek	12.6	3	3,340	9,464	7,903	7,958	3,792
3	Boat Harbour Creek	2.7	3	1,070	3,698	3,204	2,550	1,215
4	Brundige Creek	11.4	3	4,840	12,898	10,723	11,532	5,495
5	Crow Lagoon Creek	18.6	4	1,020	3,556	3,088	2,430	1,158
6	Ensheshese River	63.0	5	19,460	41,781	35,385	46,368	22,092
7	Fortune Creek	16.0	4	5,670	14,726	12,235	13,510	6,437
8	Khutzeymateen River	370.8	7	30,740	61,781	53,257	73,245	34,898
9	Lachmach River	41.6	4	11,370	26,465	22,111	27,091	12,908
10	Leverson Creek	24.0	4	6,750	17,047	14,165	16,083	7,663
11	Manzanita Cove Creek	10.5	2	5,840	15,095	12,541	13,915	6,630
12	Marion Creek	13.6	3	3,740	10,399	8,669	8,911	4,246
13	Sandy Bay Creek	11.6	5	7,820	19,293	16,044	18,633	8,878
14	Stumaun Creek	15.7	4	7,310	18,229	15,152	17,418	8,299
15	Toon River	131.9	5	21,180	44,912	38,147	50,466	24,045
16	Tracy Creek	7.7	3	1,330	4,420	3,793	3,169	1,510
17	Tsampanaknok Bay Creek	10.2	4	1,390	4,583	3,926	3,312	1,578
18	Whitley Point Creek	15.8	4	12,260	28,209	23,602	29,212	13,918
	Subtotal			**145,920**	**339,441**	**88,841**	**347,686**	**54,838**

Appendix C (cont).

					Total Smolts			
	Watershed	Area (km²)	Stream Order	Stream Length (m)	Model 1		Model 2	
Coastal Nass Area		Beta=	2					
19	Bear River	710.5	7	63,800	115,974	103,943	152,017	72,429
20	Bell Bay Creek	31.6	5	8,220	20,122	16,739	19,586	9,332
21	Bonanza Creek	31.2	4	5,760	14,922	12,397	13,724	6,539
22	Cascade Creek	19.6	4	1,380	4,556	3,904	3,288	1,567
23	Chambers Creek	89.9	4	10,010	23,761	19,812	23,851	11,364
24	Dogfish Bay Creek	21.9	4	7,550	18,731	15,572	17,989	8,571
25	Donahue Creek	70.8	5	14,610	32,735	27,497	34,811	16,586
26	Georgie River	160.4	6	29,030	58,821	50,578	69,170	32,956
27	Illiance River	91.6	5	1,560	5,040	4,297	3,717	1,771
28	Isaac Creek	14.2	3	2,840	8,271	6,928	6,767	3,224
29	Kincolith River	225.9	4	30,180	60,814	52,380	71,910	34,262
30	Kitsault River	258.6	9	25,850	53,254	45,571	61,593	29,346
31	Kshwan River	175.4	8	18,780	40,533	34,289	44,747	21,320
32	Kwinamass River	284.0	6	38,880	75,605	65,904	92,640	44,139
33	Lime Creek	27.9	4	2,230	6,768	5,704	5,313	2,532
34	Lizard Creek	32.2	4	2,650	7,809	6,551	6,314	3,008
35	Olh Creek	71.6	5	1,950	6,058	5,125	4,646	2,214
36	Pearce Island No1	17.2	3	2,990	8,632	7,223	7,124	3,394
37	Roberson Creek	8.0	3	850	3,063	2,685	2,025	965
38	Rodgers Creek	14.2	4	6,060	15,571	12,936	14,439	6,880
39	Roundy Creek	16.2	3	1,830	5,748	4,874	4,360	2,078
40	Salmon Cove Creek	24.9	4	5,340	14,004	11,637	12,724	6,062
41	Scowbank Creek	26.3	3	1,320	4,393	3,771	3,145	1,499
42	Stagoo Creek	78.0	5	27,610	56,345	48,346	65,787	31,344
43	Tauw Creek	9.4	3	240	1,102	1,050	572	272
44	Wilauks Creek	11.3	4	3,520	9,887	8,249	8,387	3,996
	Subtotal			**315,040**	**672,516**	**168,869**	**750,650**	**111,873**

Appendix C (cont).

					Total Smolts			
	Watershed	Area (km^2)	Stream Order	Stream Length (m)	Model 1		Model 2	
Lower Nass Area		Beta=	2					
45	Anliyen Creek (Greenville)	40.7	4	7,910	19,480	16,200	24,429	12,652
46	Ansedagan Creek	28.5	4	3,110	8,919	7,457	9,605	4,975
47	Anudol Creek	123.7	5	6,410	16,322	13,561	19,796	10,253
48	Burton Creek	96.0	5	280	1,247	1,175	865	448
49	Chemainuk Creek	58.1	4	15,050	33,571	28,220	46,479	24,073
50	Cugiladap Creek	6.2	3	1,290	4,311	3,704	3,984	2,063
51	Disangieq Creek	36.4	4	8,960	21,639	18,016	27,671	14,332
52	Gingietl Creek	14.7	3	1,370	4,529	3,882	4,231	2,191
53	Ginlulak Creek	43.3	4	6,820	17,195	14,289	21,062	10,909
54	Gish Creek	14.7	3	7,200	17,998	14,959	22,236	11,517
55	Giswatz Creek	13.3	3	1,670	5,331	4,534	5,158	2,671
56	Gitwinksihlkw Creek	7.0	3	1,070	3,698	3,204	3,305	1,712
57	Iknouk River	112.4	4	25,800	53,166	45,492	79,679	41,268
58	Inieth Creek	9.5	3	760	2,796	2,466	2,347	1,216
59	Ishkeenickh River	579.4	7	70,070	125,796	113,412	216,400	112,080
60	Keazoah Creek	11.5	3	770	2,826	2,490	2,378	1,232
61	Ksemamaith River	68.4	4	2,030	6,262	5,292	6,269	3,247
62	Kwiniak Creek	248.1	5	11,460	26,642	22,262	35,392	18,331
63	Kwinyarh Creek	15.6	3	1,520	4,933	4,210	4,694	2,431
64	Monkley Creek	35.7	4	7,590	18,814	15,642	23,440	12,140
65	Quilgauw Creek	37.0	4	9,600	22,936	19,113	29,648	15,356
66	Seaskinnish Creek	204.6	5	8,710	21,128	17,586	26,899	13,932
67	Tseax River	608.3	6	16,770	36,807	31,031	51,791	26,824
68	Wegiladap Creek	17.0	4	1,190	4,034	3,479	3,675	1,903
69	Welda Creek	31.3	3	710	2,645	2,342	2,193	1,136
70	Wilyayaanooth Creek	12.7	3	770	2,826	2,490	2,378	1,232
71	Zolzap Creek	32.0	5	7,810	19,273	16,026	24,120	12,492
	Subtotal			**226,700**	**505,125**	**140,571**	**700,126**	**132,006**

Appendix C (cont).

	Watershed	Area (km^2)	Stream Order	Stream Length (m)	Total Smolts Model 1		Model 2	
Upper Nass River		Beta=	2					
72	Bell-Irving River - Above Teigen	1223.5	7	121,590	203,316	190,462	351,625	163,562
73	Bell-Irving River - Bowser to Teigen	687.8	7	86,790	151,510	138,540	250,987	116,749
74	Bell-Irving River - below Bowser	456.1	7	43,720	83,648	73,358	126,434	58,812
75	Bowser River	1262.0	7	92,800	160,605	147,537	268,368	124,834
76	Cranberry River	974.8	7	143,870	235,576	223,545	416,057	193,533
77	Damdochax Creek	737.4	7	62,450	113,844	101,900	180,599	84,007
78	Hodder Creek	72.3	5	21,350	45,220	38,419	61,742	28,720
79	Kinskuch River	476.9	5	20	156	189	58	27
80	Kiteen River	885.5	7	72,480	129,544	117,045	209,604	97,500
81	Konigus Creek	471.7	6					
82	Kotsinta Creek	312.4	5	26,210	53,889	46,140	75,797	35,258
83	Kshadin Creek	105.1	5	70	414	441	202	94
84	Kwinageese River	552.3	6	152,100	247,348	235,745	439,857	204,604
85	Kwinatahl River	306.1	6	8,610	20,923	17,414	24,899	11,582
86	Meziadin River	735.6	6	110,730	187,357	174,299	320,219	148,953
87	Muskaboo Creek	614.9	6					
88	Panorama Creek	90.6	5					
89	Paw Creek	176.7	6	43,090	82,607	72,390	124,612	57,964
90	Saladamis Creek	75.0	5	17,560	38,278	32,315	50,782	23,622
91	Sallysout Creek	333.2	6	1,670	5,331	4,534	4,829	2,246
92	Sanskisoot Creek	103.3	5	30,070	60,623	52,208	86,959	40,450
93	Sanyam Creek	96.6	5	340	1,457	1,353	983	457
94	Shumal Creek	99.6	4	16,360	36,040	30,363	47,311	22,007
95	Taft Creek	474.0	6	50,000	93,921	82,975	144,595	67,260
96	Taylor River	753.2	7					
97	Tchitin River	248.2	6	16,990	37,218	31,389	49,133	22,855
98	Teigen Creek	351.7	6	64,090	116,430	104,382	185,341	86,213
99	Treaty Creek	427.1	6	51,920	97,030	85,905	150,147	69,842
100	Upper Nass River	735.6	6					
101	Vile Creek	188.0	5	49,490	93,093	82,197	143,120	66,574
102	White River	954.0	6	144,600	236,623	224,627	418,168	194,515
	Subtotal			**1,802,920**	**3,172,683**	**665,501**	**5,213,851**	**566,449**

Model 1 = Nonlinear relation between stream length and smolt density for streams from British Columbia and Southeast Alaska, Bradford et al. (1997).

Model 2 = Lachmach mean smolt density applied to Outside Area 3 and Coastal Nass; Zolzap mean smolts density applied to Lower Nass; and Toboggan Creek mean smolt densities applied to Upper Nass.

Appendix D Estimate of the required number of coho spawners assuming Model 1 smolt production (regional database).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female[5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Outside Area 3										
1	American Bay Creek	790	3	2,886	37,972	191,777	3000	128	162	0.06%
2	Bill Creek	3340	3	9,464	124,530	628,938	3000	419	126	0.20%
3	Boat Harbour Creek	1070	3	3,698	48,655	245,733	3000	164	153	0.08%
4	Brundige Creek	4840	3	12,898	169,706	857,101	3000	571	118	0.28%
5	Crow Lagoon Creek	1020	4	3,556	46,786	236,292	3000	158	154	0.08%
6	Ensheshese River	19460	5	41,781	549,747	2,776,501	3000	1,851	95	0.90%
7	Fortune Creek	5670	4	14,726	193,761	978,590	3000	652	115	0.32%
8	Khutzeymateen River	30740	7	61,781	812,904	4,105,575	3000	2,737	89	1.33%
9	Lachmach River	11370	4	26,465	348,220	1,758,685	3000	1,172	103	0.57%
10	Leverson Creek	6750	4	17,047	224,301	1,132,832	3000	755	112	0.37%
11	Manzanita Cove Creek	5840	2	15,095	198,621	1,003,137	3000	669	115	0.32%
12	Marion Creek	3740	3	10,399	136,833	691,074	3000	461	123	0.22%
13	Sandy Bay Creek	7820	5	19,293	253,860	1,282,123	3000	855	109	0.41%
14	Stumaun Creek	7310	4	18,229	239,849	1,211,361	3000	808	110	0.39%
15	Toon River	21180	5	44,912	590,952	2,984,606	3000	1,990	94	0.96%
16	Tracy Creek	1330	3	4,420	58,158	293,730	3000	196	147	0.09%
17	Tsampanaknok Bay Creek	1390	4	4,583	60,306	304,576	3000	203	146	0.10%
18	Whitley Point Creek	12260	4	28,209	371,173	1,874,611	3000	1,250	102	0.61%
	Subtotal	**145,920**		**339,441**	**4,466,334**	**22,557,243**		**15,038**	**121**	**7.29%**

Appendix D (cont).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female[5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Coastal Nass Area										
19	Bear River	63800	7	115,974	1,525,970	7,706,917	3000	5,138	81	2.49%
20	Bell Bay Creek	8220	5	20,122	264,757	1,337,156	3000	891	108	0.43%
21	Bonanza Creek	5760	4	14,922	196,337	991,599	3000	661	115	0.32%
22	Cascade Creek	1380	4	4,556	59,949	302,773	3000	202	146	0.10%
23	Chambers Creek	10010	4	23,761	312,649	1,579,033	3000	1,053	105	0.51%
24	Dogfish Bay Creek	7550	4	18,731	246,460	1,244,746	3000	830	110	0.40%
25	Donahue Creek	14610	5	32,735	430,722	2,175,362	3000	1,450	99	0.70%
26	Georgie River	29030	6	58,821	773,954	3,908,859	3000	2,606	90	1.26%
27	Illiance River	1560	5	5,040	66,311	334,903	3000	223	143	0.11%
28	Isaac Creek	2840	3	8,271	108,824	549,618	3000	366	129	0.18%
29	Kincolith River	30180	4	60,814	800,180	4,041,312	3000	2,694	89	1.31%
30	Kitsault River	25850	9	53,254	700,714	3,538,960	3000	2,359	91	1.14%
31	Kshwan River	18780	8	40,533	533,325	2,693,560	3000	1,796	96	0.87%
32	Kwinamass River	38880	6	75,605	994,800	5,024,244	3000	3,349	86	1.62%
33	Lime Creek	2230	4	6,768	89,059	449,791	3000	300	134	0.15%
34	Lizard Creek	2650	4	7,809	102,747	518,922	3000	346	131	0.17%
35	Olh Creek	1950	5	6,058	79,708	402,565	3000	268	138	0.13%
36	Pearce Island No1	2990	3	8,632	113,578	573,625	3000	382	128	0.19%
37	Roberson Creek	850	3	3,063	40,309	203,579	3000	136	160	0.07%
38	Rodgers Creek	6060	4	15,571	204,880	1,034,747	3000	690	114	0.33%
39	Roundy Creek	1830	3	5,748	75,636	382,000	3000	255	139	0.12%
40	Salmon Cove Creek	5340	4	14,004	184,264	930,627	3000	620	116	0.30%
41	Scowbank Creek	1320	3	4,393	57,799	291,914	3000	195	147	0.09%
42	Stagoo Creek	27610	5	56,345	741,385	3,744,368	3000	2,496	90	1.21%
43	Tauw Creek	240	3	1,102	14,493	73,199	3000	49	203	0.02%
44	Wilauks Creek	3520	4	9,887	130,092	657,033	3000	438	124	0.21%
	Sub total	**315,040**		**672,516**	**8,848,900**	**44,691,414**		**29,794**	**120**	**14.44%**

Appendix D (cont).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female[5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Lower Nass Area										
45	Anliyen Creek (Greenville)	7910	4	19,480	256,319	1,294,540	2500	1,036	131	0.50%
46	Ansedagan Creek	3110	4	8,919	117,354	592,697	2500	474	152	0.23%
47	Anudol Creek	6410	5	16,322	214,769	1,084,693	2500	868	135	0.42%
48	Burton Creek	280	5	1,247	16,402	82,836	2500	66	237	0.03%
49	Chemainuk Creek	15050	4	33,571	441,719	2,230,903	2500	1,785	119	0.87%
50	Cugiladap Creek	1290	3	4,311	56,718	286,455	2500	229	178	0.11%
51	Disangieq Creek	8960	4	21,639	284,719	1,437,976	2500	1,150	128	0.56%
52	Gingietl Creek	1370	3	4,529	59,592	300,969	2500	241	176	0.12%
53	Ginlulak Creek	6820	4	17,195	226,254	1,142,698	2500	914	134	0.44%
54	Gish Creek	7200	3	17,998	236,809	1,196,007	2500	957	133	0.46%
55	Giswatz Creek	1670	3	5,331	70,139	354,238	2500	283	170	0.14%
56	Gitwinksihlkw Creek	1070	3	3,698	48,655	245,733	2500	197	184	0.10%
57	Iknouk River	25800	4	53,166	699,554	3,533,099	2500	2,826	110	1.37%
58	Inieth Creek	760	3	2,796	36,792	185,820	2500	149	196	0.07%
59	Ishkeenickh River	70070	7	125,796	1,655,216	8,359,679	2500	6,688	95	3.24%
60	Keazoah Creek	770	3	2,826	37,186	187,810	2500	150	195	0.07%
61	Ksemamaith River	2030	4	6,262	82,400	416,162	2500	333	164	0.16%
62	Kwiniak Creek	11460	5	26,642	350,552	1,770,464	2500	1,416	124	0.69%
63	Kwinyarh Creek	1520	3	4,933	64,908	327,818	2500	262	173	0.13%
64	Monkley Creek	7590	4	18,814	247,559	1,250,296	2500	1,000	132	0.48%
65	Quilgauw Creek	9600	4	22,936	301,795	1,524,216	2500	1,219	127	0.59%
66	Seaskinnish Creek	8710	5	21,128	278,003	1,404,053	2500	1,123	129	0.54%
67	Tseax River	16770	6	36,807	484,302	2,445,968	2500	1,957	117	0.95%
68	Wegiladap Creek	1190	4	4,034	53,084	268,101	2500	214	180	0.10%
69	Welda Creek	710	3	2,645	34,808	175,799	2500	141	198	0.07%
70	Wilyayaanooth Creek	770	3	2,826	37,186	187,810	2500	150	195	0.07%
71	Zolzap Creek	7810	5	19,273	253,587	1,280,742	2500	1,025	131	0.50%
	Sub total	**226,700**		**505,125**	**6,646,381**	**33,567,582**		**26,854**	**153**	**13.02%**

Appendix D (cont).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female[5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Upper Nass Area										
72	Bell-Irving River -Above Teigen	121590	7	203,316	2,675,215	13,511,187	2500	10,809	89	5.24%
73	Bell-Irving River - Bowser to Teigen	86790	7	151,510	1,993,547	10,068,420	2500	8,055	93	3.90%
74	Bell-Irving River -below Bowser	43720	7	83,648	1,100,627	5,558,720	2500	4,447	102	2.16%
75	Bowser River	92800	7	160,605	2,113,227	10,672,863	2500	8,538	92	4.14%
76	Cranberry River	143870	7	235,576	3,099,682	15,654,959	2500	12,524	87	6.07%
77	Damdochax Creek	62450	7	113,844	1,497,947	7,565,389	2500	6,052	97	2.93%
78	Hodder Creek	21350	5	45,220	595,000	3,005,050	2500	2,404	113	1.17%
79	Kinskuch River	20	5	156	2,051	10,358	2500	8	414	0.00%
80	Kiteen River	72480	7	129,544	1,704,523	8,608,703	2500	6,887	95	3.34%
81	Konigus Creek		6							
82	Kotsinta Creek	26210	5	53,889	709,062	3,581,120	2500	2,865	109	1.39%
83	Kshadin Creek	70	5	414	5,447	27,510	2500	22	314	0.01%
84	Kwinageese River	152100	6	247,348	3,254,576	16,437,255	2500	13,150	86	6.37%
85	Kwinatahl River	8610	6	20,923	275,308	1,390,446	2500	1,112	129	0.54%
86	Meziadin River	110730	6	187,357	2,465,223	12,450,622	2500	9,960	90	4.83%
87	Muskaboo Creek		6							
88	Panorama Creek		5							
89	Paw Creek	43090	6	82,607	1,086,938	5,489,585	2500	4,392	102	2.13%

Appendix D (cont).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female [5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Upper Nass Area (cont)										
90	Saladamis Creek	17560	5	38,278	503,659	2,543,732	2500	2,035	116	0.99%
91	Sallysout Creek	1670	6	5,331	70,139	354,238	2500	283	170	0.14%
92	Sanskisoot Creek	30070	5	60,623	797,677	4,028,671	2500	3,223	107	1.56%
93	Sanyam Creek	340	5	1,457	19,174	96,839	2500	77	228	0.04%
94	Shumal Creek	16360	4	36,040	474,207	2,394,986	2500	1,916	117	0.93%
95	Taft Creek	50000	6	93,921	1,235,807	6,241,451	2500	4,993	100	2.42%
96	Taylor River		7							
97	Tchitin River	16990	6	37,218	489,704	2,473,255	2500	1,979	116	0.96%
98	Teigen Creek	64090	6	116,430	1,531,980	7,737,272	2500	6,190	97	3.00%
99	Treaty Creek	51920	6	97,030	1,276,709	6,448,023	2500	5,158	99	2.50%
100	Upper Nass River		6							
101	Vile Creek	49490	5	93,093	1,224,911	6,186,418	2500	4,949	100	2.40%
102	White River	144600	6	236,623	3,113,460	15,724,544	2500	12,580	87	6.10%
	Sub total	**1,802,920**		**3,172,683**	**41,745,832**	**210,837,537**		**168,670**	**129**	**65.25%**

Appendix E Estimate of the required number of coho spawners assuming Model 2 smolt production (local indicators).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female[5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Outside Area 3										
1	American Bay Creek	790	3	1,882	24,833	125,419	3000	84	106	0.03%
2	Bill Creek	3340	3	7,958	104,990	530,254	3000	354	106	0.12%
3	Boat Harbour Creek	1070	3	2,550	33,635	169,872	3000	113	106	0.04%
4	Brundige Creek	4840	3	11,532	152,142	768,392	3000	512	106	0.17%
5	Crow Lagoon Creek	1020	4	2,430	32,063	161,934	3000	108	106	0.04%
6	Ensheshese River	19460	5	46,368	611,710	3,089,445	3000	2,060	106	0.67%
7	Fortune Creek	5670	4	13,510	178,232	900,162	3000	600	106	0.20%
8	Khutzeymateen River	30740	7	73,245	966,288	4,880,244	3000	3,253	106	1.06%
9	Lachmach River	11370	4	27,091	357,407	1,805,087	3000	1,203	106	0.39%
10	Leverson Creek	6750	4	16,083	212,181	1,071,622	3000	714	106	0.23%
11	Manzanita Cove Creek	5840	2	13,915	183,576	927,151	3000	618	106	0.20%
12	Marion Creek	3740	3	8,911	117,564	593,758	3000	396	106	0.13%
13	Sandy Bay Creek	7820	5	18,633	245,816	1,241,493	3000	828	106	0.27%
14	Stumaun Creek	7310	4	17,418	229,784	1,160,526	3000	774	106	0.25%
15	Toon River	21180	5	50,466	665,777	3,362,510	3000	2,242	106	0.73%
16	Tracy Creek	1330	3	3,169	41,808	211,149	3000	141	106	0.05%
17	Tsampanaknok Bay Creek	1390	4	3,312	43,694	220,675	3000	147	106	0.05%
18	Whitley Point Creek	12260	4	29,212	385,384	1,946,382	3000	1,298	106	0.42%
	Subtotal	**145,920**		**347,686**	**4,586,883**	**23,166,077**		**15,444**	**106**	**5.04%**

Appendix E (cont).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female[5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Coastal Nass Area										
19	Bear River	63800	7	152,017	2,005,504	10,128,808	3000	6,753	106	2.20%
20	Bell Bay Creek	8220	5	19,586	258,389	1,304,997	3000	870	106	0.28%
21	Bonanza Creek	5760	4	13,724	181,061	914,450	3000	610	106	0.20%
22	Cascade Creek	1380	4	3,288	43,379	219,087	3000	146	106	0.05%
23	Chambers Creek	10010	4	23,851	314,657	1,589,175	3000	1,059	106	0.35%
24	Dogfish Bay Creek	7550	4	17,989	237,328	1,198,629	3000	799	106	0.26%
25	Donahue Creek	14610	5	34,811	459,254	2,319,465	3000	1,546	106	0.50%
26	Georgie River	29030	6	69,170	912,536	4,608,767	3000	3,073	106	1.00%
27	Illiance River	1560	5	3,717	49,037	247,664	3000	165	106	0.05%
28	Isaac Creek	2840	3	6,767	89,273	450,875	3000	301	106	0.10%
29	Kincolith River	30180	4	71,910	948,685	4,791,339	3000	3,194	106	1.04%
30	Kitsault River	25850	9	61,593	812,575	4,103,914	3000	2,736	106	0.89%
31	Kshwan River	18780	8	44,747	590,335	2,981,489	3000	1,988	106	0.65%
32	Kwinamass River	38880	6	92,640	1,222,163	6,172,540	3000	4,115	106	1.34%
33	Lime Creek	2230	4	5,313	70,098	354,032	3000	236	106	0.08%
34	Lizard Creek	2650	4	6,314	83,301	420,711	3000	280	106	0.09%
35	Olh Creek	1950	5	4,646	61,297	309,580	3000	206	106	0.07%
36	Pearce Island No1	2990	3	7,124	93,988	474,689	3000	316	106	0.10%
37	Roberson Creek	850	3	2,025	26,719	134,945	3000	90	106	0.03%
38	Rodgers Creek	6060	4	14,439	190,491	962,078	3000	641	106	0.21%
39	Roundy Creek	1830	3	4,360	57,525	290,529	3000	194	106	0.06%
40	Salmon Cove Creek	5340	4	12,724	167,859	847,772	3000	565	106	0.18%
41	Scowbank Creek	1320	3	3,145	41,493	209,562	3000	140	106	0.05%
42	Stagoo Creek	27610	5	65,787	867,899	4,383,329	3000	2,922	106	0.95%
43	Tauw Creek	240	3	572	7,544	38,102	3000	25	106	0.01%
44	Wilauks Creek	3520	4	8,387	110,648	558,831	3000	373	106	0.12%
	Sub total	**315,040**		**750,650**	**9,903,041**	**50,015,357**		**33,344**	**106**	**10.88%**

Appendix E (cont).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female [5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Lower Nass Area										
45	Anliyen Creek (Greenville)	7910	4	24,429	322,279	1,627,671	2500	1,302	165	0.43%
46	Ansedagan Creek	3110	4	9,605	126,711	639,957	2500	512	165	0.17%
47	Anudol Creek	6410	5	19,796	261,164	1,319,011	2500	1,055	165	0.34%
48	Burton Creek	280	5	865	11,408	57,617	2500	46	165	0.02%
49	Chemainuk Creek	15050	4	46,479	613,186	3,096,897	2500	2,478	165	0.81%
50	Cugiladap Creek	1290	3	3,984	52,559	265,448	2500	212	165	0.07%
51	Disangieq Creek	8960	4	27,671	365,059	1,843,734	2500	1,475	165	0.48%
52	Gingietl Creek	1370	3	4,231	55,818	281,910	2500	226	165	0.07%
53	Ginlulak Creek	6820	4	21,062	277,869	1,403,378	2500	1,123	165	0.37%
54	Gish Creek	7200	3	22,236	293,351	1,481,572	2500	1,185	165	0.39%
55	Giswatz Creek	1670	3	5,158	68,041	343,642	2500	275	165	0.09%
56	Gitwinksihlkw Creek	1070	3	3,305	43,595	220,178	2500	176	165	0.06%
57	Iknouk River	25800	4	79,679	1,051,175	5,308,966	2500	4,247	165	1.39%
58	Inieth Creek	760	3	2,347	30,965	156,388	2500	125	165	0.04%
59	Ishkeenickh River	70070	7	216,400	2,854,878	14,418,576	2500	11,535	165	3.76%
60	Keazoah Creek	770	3	2,378	31,372	158,446	2500	127	165	0.04%
61	Ksemamaith River	2030	4	6,269	82,709	417,721	2500	334	165	0.11%
62	Kwiniak Creek	11460	5	35,392	466,917	2,358,169	2500	1,887	165	0.62%
63	Kwinyarh Creek	1520	3	4,694	61,930	312,776	2500	250	165	0.08%
64	Monkley Creek	7590	4	23,440	309,241	1,561,824	2500	1,249	165	0.41%
65	Quilgauw Creek	9600	4	29,648	391,135	1,975,429	2500	1,580	165	0.52%
66	Seaskinnish Creek	8710	5	26,899	354,874	1,792,291	2500	1,434	165	0.47%
67	Tseax River	16770	6	51,791	683,264	3,450,828	2500	2,761	165	0.90%
68	Wegiladap Creek	1190	4	3,675	48,484	244,871	2500	196	165	0.06%
69	Welda Creek	710	3	2,193	28,928	146,099	2500	117	165	0.04%
70	Wilyayaanooth Creek	770	3	2,378	31,372	158,446	2500	127	165	0.04%
71	Zolzap Creek	7810	5	24,120	318,205	1,607,094	2500	1,286	165	0.42%
	Sub total	**226,700**		**700,126**	**9,236,490**	**46,648,940**		**37,319**	**165**	**12.18%**

Appendix E (cont).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female[5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Upper Nass Area										
72	Bell-Irving River -Above Teigen	121590	7	351,625	4,638,856	23,428,563	2500	18,743	154	6.12%
73	Bell-Irving River - Bowser to Teigen	86790	7	250,987	3,311,179	16,723,127	2500	13,379	154	4.37%
74	Bell-Irving River -below Bowser	43720	7	126,434	1,667,989	8,424,186	2500	6,739	154	2.20%
75	Bowser River	92800	7	268,368	3,540,470	17,881,163	2500	14,305	154	4.67%
76	Cranberry River	143870	7	416,057	5,488,874	27,721,584	2500	22,177	154	7.24%
77	Damdochax Creek	62450	7	180,599	2,382,569	12,033,175	2500	9,627	154	3.14%
78	Hodder Creek	21350	5	61,742	814,537	4,113,824	2500	3,291	154	1.07%
79	Kinskuch River	20	5	58	763	3,854	2500	3	154	0.00%
80	Kiteen River	72480	7	209,604	2,765,229	13,965,805	2500	11,173	154	3.65%
81	Konigus Creek		6							
82	Kotsinta Creek	26210	5	75,797	999,954	5,050,273	2500	4,040	154	1.32%
83	Kshadin Creek	70	5	202	2,671	13,488	2500	11	154	0.00%
84	Kwinageese River	152100	6	439,857	5,802,861	29,307,381	2500	23,446	154	7.65%
85	Kwinatahl River	8610	6	24,899	328,485	1,659,017	2500	1,327	154	0.43%
86	Meziadin River	110730	6	320,219	4,224,529	21,336,005	2500	17,069	154	5.57%
87	Muskaboo Creek		6							
88	Panorama Creek		5							
89	Paw Creek	43090	6	124,612	1,643,953	8,302,795	2500	6,642	154	2.17%

Appendix E (cont).

	Watershed	Stream Length (m)	Stream Order	Smolts1 Produced	Fry2 Produced	Required3 Eggs	Female[5] fecundity	Spawners	Spawner/ km	Percent of Total Nass escapement
					egg-fry =	19.8%				
				fry-smolt =	7.6%					
Upper Nass Area (cont)										
90	Saladamis Creek	17560	5	50,782	669,942	3,383,548	2500	2,707	154	0.88%
91	Sallysout Creek	1670	6	4,829	63,713	321,784	2500	257	154	0.08%
92	Sanskisoot Creek	30070	5	86,959	1,147,219	5,794,036	2500	4,635	154	1.51%
93	Sanyam Creek	340	5	983	12,972	65,513	2500	52	154	0.02%
94	Shumal Creek	16360	4	47,311	624,161	3,152,326	2500	2,522	154	0.82%
95	Taft Creek	50000	6	144,595	1,907,581	9,634,248	2500	7,707	154	2.52%
96	Taylor River		7							
97	Tchitin River	16990	6	49,133	648,196	3,273,717	2500	2,619	154	0.85%
98	Teigen Creek	64090	6	185,341	2,445,137	12,349,179	2500	9,879	154	3.22%
99	Treaty Creek	51920	6	150,147	1,980,832	10,004,203	2500	8,003	154	2.61%
100	Upper Nass River		6							
101	Vile Creek	49490	5	143,120	1,888,124	9,535,978	2500	7,629	154	2.49%
102	White River	144600	6	418,168	5,516,724	27,862,244	2500	22,290	154	7.28%
	Sub total	**1,802,920**		**5,213,851**	**68,784,319**	**347,395,552**		**277,916**	**154**	**71.90%**

Appendix F Estimation of total coho return and allowable harvest rates for assumed survival rates.

System	Fecundity (per spawner)	Fry per Spawner	Fry to smolt survival	Smolts per Spawner	Predicted Smolt Yield (Model 1)	Smolt Model Spawner Requirements	Total Return of Adults	Allowable Harvest Rate
	Egg to Fry Survival =		19.8%					
	Fry to Smolt Survival =		7.6%					
	Smolt to Adult Survival =		10%					
Outside Area 3								
American Bay Creek	1500	297	0.076	22.57	2,886	128	289	55.7%
Bill Creek	1500	297	0.076	22.57	9,464	419	946	55.7%
Boat Harbour Creek	1500	297	0.076	22.57	3,698	164	370	55.7%
Brundige Creek	1500	297	0.076	22.57	12,898	571	1,290	55.7%
Crow Lagoon Creek	1500	297	0.076	22.57	3,556	158	356	55.7%
Ensheshese River	1500	297	0.076	22.57	41,781	1,851	4,178	55.7%
Fortune Creek	1500	297	0.076	22.57	14,726	652	1,473	55.7%
Khutzeymateen River	1500	297	0.076	22.57	61,781	2,737	6,178	55.7%
Lachmach River	1500	297	0.076	22.57	26,465	1,172	2,646	55.7%
Leverson Creek	1500	297	0.076	22.57	17,047	755	1,705	55.7%
Manzanita Cove Creek	1500	297	0.076	22.57	15,095	669	1,510	55.7%
Marion Creek	1500	297	0.076	22.57	10,399	461	1,040	55.7%
Sandy Bay Creek	1500	297	0.076	22.57	19,293	855	1,929	55.7%
Stumaun Creek	1500	297	0.076	22.57	18,229	808	1,823	55.7%
Toon River	1500	297	0.076	22.57	44,912	1,990	4,491	55.7%
Tracy Creek	1500	297	0.076	22.57	4,420	196	442	55.7%
Tsampanaknok Bay Creek	1500	297	0.076	22.57	4,583	203	458	55.7%
Whitley Point Creek	1500	297	0.076	22.57	28,209	1,250	2,821	55.7%
Sub total					**339,441**	**15,038**	**33,944**	

Appendix F (cont).

System	Fecundity (per spawner)	Fry per Spawner	Fry to smolt survival	Smolts per Spawner	Predicted Smolt Yield (Model 1)	Smolt Model Spawner Requirements	Total Return of Adults	Allowable Harvest Rate
	Egg to Fry Survival =		19.8%					
	Fry to Smolt Survival =		7.6%					
	Smolt to Adult Survival =		10%					
Coastal Nass Area								
Bear River	1500	297	0.076	22.57	115,974	5,138	11,597	55.7%
Bell Bay Creek	1500	297	0.076	22.57	20,122	891	2,012	55.7%
Bonanza Creek	1500	297	0.076	22.57	14,922	661	1,492	55.7%
Cascade Creek	1500	297	0.076	22.57	4,556	202	456	55.7%
Chambers Creek	1500	297	0.076	22.57	23,761	1,053	2,376	55.7%
Dogfish Bay Creek	1500	297	0.076	22.57	18,731	830	1,873	55.7%
Donahue Creek	1500	297	0.076	22.57	32,735	1,450	3,273	55.7%
Georgie River	1500	297	0.076	22.57	58,821	2,606	5,882	55.7%
Illiance River	1500	297	0.076	22.57	5,040	223	504	55.7%
Isaac Creek	1500	297	0.076	22.57	8,271	366	827	55.7%
Kincolith River	1500	297	0.076	22.57	60,814	2,694	6,081	55.7%
Kitsault River	1500	297	0.076	22.57	53,254	2,359	5,325	55.7%
Kshwan River	1500	297	0.076	22.57	40,533	1,796	4,053	55.7%
Kwinamass River	1500	297	0.076	22.57	75,605	3,349	7,560	55.7%
Lime Creek	1500	297	0.076	22.57	6,768	300	677	55.7%
Lizard Creek	1500	297	0.076	22.57	7,809	346	781	55.7%
Olh Creek	1500	297	0.076	22.57	6,058	268	606	55.7%
Pearce Island No1	1500	297	0.076	22.57	8,632	382	863	55.7%
Roberson Creek	1500	297	0.076	22.57	3,063	136	306	55.7%
Rodgers Creek	1500	297	0.076	22.57	15,571	690	1,557	55.7%
Roundy Creek	1500	297	0.076	22.57	5,748	255	575	55.7%
Salmon Cove Creek	1500	297	0.076	22.57	14,004	620	1,400	55.7%
Scowbank Creek	1500	297	0.076	22.57	4,393	195	439	55.7%
Stagoo Creek	1500	297	0.076	22.57	56,345	2,496	5,635	55.7%
Tauw Creek	1500	297	0.076	22.57	1,102	49	110	55.7%
Wilauks Creek	1500	297	0.076	22.57	9,887	438	989	55.7%
Sub total					**672,516**	**29,794**	**67,252**	

Appendix F (cont).

System	Fecundity (per spawner)	Fry per Spawner	Fry to smolt survival	Smolts per Spawner	Predicted Smolt Yield (Model 1)	Smolt Model Spawner Requirements	Total Return of Adults	Allowable Harvest Rate
	Egg to Fry Survival =		19.8%					
	Fry to Smolt Survival =		7.6%					
Lower Nass Area	Smolt to Adult Survival =		10%					
Anliyen Creek (Greenville)	1250	248	0.076	18.81	19,480	1,036	1,948	46.8%
Ansedagan Creek	1250	248	0.076	18.81	8,919	474	892	46.8%
Anudol Creek	1250	248	0.076	18.81	16,322	868	1,632	46.8%
Burton Creek	1250	248	0.076	18.81	1,247	66	125	46.8%
Chemainuk Creek	1250	248	0.076	18.81	33,571	1,785	3,357	46.8%
Cugiladap Creek	1250	248	0.076	18.81	4,311	229	431	46.8%
Disangieq Creek	1250	248	0.076	18.81	21,639	1,150	2,164	46.8%
Gingietl Creek	1250	248	0.076	18.81	4,529	241	453	46.8%
Ginlulak Creek	1250	248	0.076	18.81	17,195	914	1,720	46.8%
Gish Creek	1250	248	0.076	18.81	17,998	957	1,800	46.8%
Giswatz Creek	1250	248	0.076	18.81	5,331	283	533	46.8%
Gitwinksihlkw Creek	1250	248	0.076	18.81	3,698	197	370	46.8%
Iknouk River	1250	248	0.076	18.81	53,166	2,826	5,317	46.8%
Inieth Creek	1250	248	0.076	18.81	2,796	149	280	46.8%
Ishkeenickh River	1250	248	0.076	18.81	125,796	6,688	12,580	46.8%
Keazoah Creek	1250	248	0.076	18.81	2,826	150	283	46.8%
Ksemamaith River	1250	248	0.076	18.81	6,262	333	626	46.8%
Kwiniak Creek	1250	248	0.076	18.81	26,642	1,416	2,664	46.8%
Kwinyarh Creek	1250	248	0.076	18.81	4,933	262	493	46.8%
Monkley Creek	1250	248	0.076	18.81	18,814	1,000	1,881	46.8%
Quilgauw Creek	1250	248	0.076	18.81	22,936	1,219	2,294	46.8%
Seaskinnish Creek	1250	248	0.076	18.81	21,128	1,123	2,113	46.8%
Tseax River	1250	248	0.076	18.81	36,807	1,957	3,681	46.8%
Wegiladap Creek	1250	248	0.076	18.81	4,034	214	403	46.8%
Welda Creek	1250	248	0.076	18.81	2,645	141	265	46.8%
Wilyayaanooth Creek	1250	248	0.076	18.81	2,826	150	283	46.8%
Zolzap Creek	1250	248	0.076	18.81	19,273	1,025	1,927	46.8%
Sub total					**505,125**	**26,854**	**50,512**	

Appendix F (cont).

System	Fecundity (per spawner)	Fry per Spawner	Fry to smolt survival	Smolts per Spawner	Predicted Smolt Yield (Model 1)	Smolt Model Spawner Requirements	Total Return of Adults	Allowable Harvest Rate
	Egg to Fry Survival =		19.8%					
	Fry to Smolt Survival =		7.6%					
	Smolt to Adult Survival =		10%					
Upper Nass Area								
Bell-Irving River - Above Teigen	1250	248	0.076	18.81	203,316	10,809	20,332	46.8%
Bell-Irving River - Bowser to Teigen	1250	248	0.076	18.81	151,510	8,055	15,151	46.8%
Bell-Irving River - below Bowser	1250	248	0.076	18.81	83,648	4,447	8,365	46.8%
Bowser River	1250	248	0.076	18.81	160,605	8,538	16,061	46.8%
Cranberry River	1250	248	0.076	18.81	235,576	12,524	23,558	46.8%
Damdochax Creek	1250	248	0.076	18.81	113,844	6,052	11,384	46.8%
Hodder Creek	1250	248	0.076	18.81	45,220	2,404	4,522	46.8%
Kinskuch River	1250	248	0.076	18.81	156	8	16	46.8%
Kiteen River	1250	248	0.076	18.81	129,544	6,887	12,954	46.8%
Konigus Creek								
Kotsinta Creek	1250	248	0.076	18.81	53,889	2,865	5,389	46.8%
Kshadin Creek	1250	248	0.076	18.81	414	22	41	46.8%
Kwinageese River	1250	248	0.076	18.81	247,348	13,150	24,735	46.8%
Kwinatahl River	1250	248	0.076	18.81	20,923	1,112	2,092	46.8%
Meziadin River	1250	248	0.076	18.81	187,357	9,960	18,736	46.8%
Muskaboo Creek								
Panorama Creek								
Paw Creek	1250	248	0.076	18.81	82,607	4,392	8,261	46.8%

Appendix F (cont).

System	Fecundity (per spawner)	Fry per Spawner	Fry to smolt survival	Smolts per Spawner	Predicted Smolt Yield (Model 1)	Smolt Model Spawner Requirements	Total Return of Adults	Allowable Harvest Rate
	Egg to Fry Survival =		19.8%					
	Fry to Smolt Survival =		7.6%					
	Smolt to Adult Survival =		10%					
Upper Nass Area (cont)								
Saladamis Creek	1250	248	0.076	18.81	38,278	2035	3,828	46.8%
Sallysout Creek	1250	248	0.076	18.81	5,331	283	533	46.8%
Sanskisoot Creek	1250	248	0.076	18.81	60,623	3,223	6,062	46.8%
Sanyam Creek	1250	248	0.076	18.81	1,457	77	146	46.8%
Shumal Creek	1250	248	0.076	18.81	36,040	1,916	3,604	46.8%
Taft Creek	1250	248	0.076	18.81	93,921	4,993	9,392	46.8%
Taylor River								
Tchitin River	1250	248	0.076	18.81	37,218	1,979	3,722	46.8%
Teigen Creek	1250	248	0.076	18.81	116,430	6,190	11,643	46.8%
Treaty Creek	1250	248	0.076	18.81	97,030	5,158	9,703	46.8%
Upper Nass River								
Vile Creek	1250	248	0.076	18.81	93,093	4,949	9,309	46.8%
White River	1250	248	0.076	18.81	236,623	12,580	23,662	46.8%
Sub total					**2,532,001**	**134,609**	**253,200**	