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Carrying Capacity of Coho Salmon Streams

D.E. Marshall and E.W. Britton

Department of Fisheries and Oceans
Salmonid Enhancement Program
Vancouver, British Columbia V6B 5G3

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D.E. Marshall and E.W. Britton

Department of Fisheries and Oceans

Salmonid Enhancement Program

555 West Hastings Street

Vancouver, British Columbia

V6B 5G3

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ABSTRACT

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

The carrying capacity of coho salmon streams was analyzed by comparing coho smolt yields (expressed as numbers and biomass) with rearing space (expressed as length and area of stream accessible to spawners). The two smolt yield variables and the two rearing space variables were analyzed for a linear relationship using the equation $y = a + bx$, and for a curvilinear relationship using the equation $y = ax^b$. The goodness of fit (r) of data points to the two regression types was then compared. The data were obtained from the literature and unpublished sources, and included one or more years of smolt output data, and data on length and/or area for 21 streams, 2 ponds and 2 side channels.

High correlations ($r \geq 0.70$, $p \leq 0.05$) were obtained for all comparative tests, indicating that all four variables provided a good measure of carrying capacity. Small but consistent differences in the r values indicated the following trends or tendencies in the data:

(a) The curvilinear equation $y = ax^b$ is superior to the linear equation $y = a + bx$ in describing the relationship between smolt yield and rearing space for the four variables tested.

(b) Smolt biomass is superior to numbers in representing the carrying capacity.

(c) For small streams less than 4 km in length or less than 20,000 m^2 in area, stream area is more representative of carrying capacity than stream length. For streams of all sizes analyzed collectively using the curvilinear equation, no difference exists between stream area or length as a measure of carrying capacity.

By applying to the equation $y = ax^b$, a given value (x) for stream length or area and the values derived for the constants a and b, the corresponding mean annual smolt yields in numbers or biomass can be calculated. This revealed that, compared to small streams, large streams are more productive per unit length but less productive per unit area. A trend was also apparent toward larger mean smolt size with increasing stream size.

It was evident from this analysis that a third rearing space variable, namely stream width, was involved in determining carrying capacity of coho salmon streams.

Key words: coho salmon, carrying capacity, smolts, rearing space.

RÉSUMÉ

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

La capacité biotique des cours d'eau à saumon coho a été analysée par la comparaison des rendements en coho à l'état de smolts (exprimés en nombre et en biomasse) avec l'espace d'élevage (exprimé en longueur et superficie du cours d'eau accessible aux géniteurs. Les deux variables relatives au rendement en smolt et les deux variables relatives à l'espace d'élevage ont été analysées en vue d'établir une relation linéaire au moyen de l'équation $y = a + bx$, et une relation curviligne à partir de l'équation $y = ax^b$. La qualité de l'ajustement (r) des points de données aux deux types de régression a ensuite été comparée. Les données provenaient de la littérature et de sources inédites, et comportaient des données sur le nombre de smolts pour une ou plusieurs années, et des données sur la longueur et (ou) la superficie pour 21 cours d'eau, 2 étangs et 2 chenaux latéraux.

Toutes les analyses comparatives étaient fortement corrélées ($r > 0,70$, $p \leq 0,05$), ce qui montre que les quatre variables donnaient une bonne mesure de la capacité biotique. Des différrences faibles mais constantes au niveau des valeurs r ont montré les tendances suivantes au niveau des données:

a) L'équation curviligne $y = ax^b$ est supérieure à l'équation linéaire $y = a + bx$ pour décrire le rapport entre le rendement en smolt et l'espace d'élevage pour les quatre variables étudiées.

b) La biomasse des smolts est supérieure au nombre au niveau de la représentation de la capacité biotique.

c) Dans le cas de petits cours d'eau moins de 4 km de longueur ou de superficie inférieure à 20 000 m^2, la superficie du cours d'eau est plus représentative de la capacité biotique que la longueur du cours d'eau. Dans le cas de cours d'eau de dimensions diverses étudiés collectivement au moyen de l'équation curviligne, il n'existe aucune différence entre la superficie du cours d'eau ou sa longueur comme mesure de la capacité biotique.

En appliquant à l'équation $y = ax^b$ une valeur donnée (x) pour la longueur du cours d'eau ou sa superficie et les valeurs dérivées pour les constantes a et b, il est possible de calculer les rendements moyens annuels correspondants en smolts en nombre ou en biomasse. Ces données montrent que par rapport aux petits cours d'eau, les grands cours d'eau sont plus productifs par unité de longueur mais moins productifs par unité de surface. La taille moyenne des smolts avait tendance à être plus grande lorsque les dimensions du cours d'eau augmentaient.

Il ressort de cette analyse qu'on devait tenir compte d'une troisiéme variable relative à l'espace d'élevage, soit la largeur du cours d'eau, pour déterminer la capacité biotique des cours d'eau fréquentés par les saumons cohos.

Mots-clés: saumon coho, capacité biotique, smolts, espace d'élevage.

PREFACE

This report is based on an initial draft completed in 1980, with records dating back to the 1927-1979 period. Although more current data were available at the time of final report preparation, we felt that the manuscript was publishable as is. Over the past years, the original draft was made available to the biologists of the Department of Fisheries and Oceans, and has proven useful in salmon habitat management.

INTRODUCTION

In this report, stream carrying capacity for coho salmon (Oncorhynchus kisutch was analyzed based on a comparison of coho salmon smolt yields with rearing space. The four variables used to describe this relationship were smolt numbers and biomass, and length and area of stream accessible to spawners. Other factors that might influence carrying capacity, such as nutrient level, stream gradient, temperature and flow, were not examined.

The relationships between smolt yield (expressed as numbers and biomass) and rearing space (expressed as length and area of stream) were examined by plotting each smolt yield variable (y) against each rearing space variable (x) for a number of streams. The goodness of fit (r) of data points, obtained using a linear relationship ($y = a + bx$), was then compared with that using a curvilinear or parabolic relationship ($y = ax^b$).

DEFINITION OF CARRYING CAPACITY

Burns (1971) provided the following definition of stream carrying capacity:

> "Carrying capacity is defined 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. Spawning salmonids in coastal streams are thought to produce enough progeny to fill streams to carrying capacity. This assumption is supported by observations of high rates of emigration and mortality of fry shortly after emergence from the spawning bed. Since a section of stream can accommodate only a limited number of territories, surplus fish are displaced. Displacement distributes fish to parts of the system remote from spawning grounds, thus ensuring that most of the area and productivity of the system is utilized. Even in the absence of excess fry production, receding summer stream flow limits habitat and practically insures that streams are filled to carrying capacity. Survival and growth of fishes in those streams are density dependent, or have density dependent components. The stream's carrying capacity limits the number and weight of salmonid smolts ultimately produced."

Carrying capacity, for the purposes of this analysis, is defined simply as the mean annual smolt yield, either in numbers or as biomass, that a stream produces when adequately seeded by spawners. For any given stream, considerable variation in annual smolt yield may occur due to various natural causes. However, it is emphasized that carrying capacity cannot be achieved without adequate spawning.

DETERMINATION OF THE BEST PARAMETERS FOR DEFINING CARRYING CAPACITY

Various studies have shown that carrying capacity of streams is related to a number of parameters, among them stream length, area, volume, flow, gradient, number of feeding locations and food supply. Of these parameters, stream length and area were the most frequently encountered indicators. Consequently, they were considered as the best parameters for defining carrying capacity in our analysis. Some of the relevant studies which helped develop this concept are reviewed briefly in the following sections.

Burns (1971) compared three stream space variables (surface area, volume and flow) with salmonid standing crops in seven small streams in northern California (stream length 3.1 km or less and minimum flow 0.037 m^3/s (1.3 cfs) or less). This comparison was to determine which space variable was most closely associated with carrying capacity. He found that stream surface area provided the best correlation with absolute biomass (total biomass for the stream) (r = 0.898), followed by stream volume (r = 0.837). Stream flow, however, showed no relationship with biomass (r = 0.003). Volume of streambed sediments, total dissolved solids, alkalinity and total phosphate in six of the streams tested for these variables, were also not satisfactory predictors of carrying capacity.

In a similar study on an individual stream, Burns (1971) compared juvenile densities in the spring and fall over a three year period. He again found the best correlation between absolute biomass and surface area (r = 0.868), followed in this study by stream flow (r = 0.836), volume (r = 0.790) and a fourth variable, stream length (r = 0.656).

Chapman (1965) studied juvenile coho populations in three small Oregon streams. He reported that annual net production (standing crop adjusted for growth and mortality) differed greatly among the streams in any given year, but did not differ significantly on a per unit area basis. Chapman suggested that factors such as spatial needs and/or food supply were involved in regulating annual net production.

Mason and Chapman (1965) found coho production in Oregon streams to be correlated more strongly with available stream area than with other parameters.

Lister (MS 1968b) suggested that stream productivity was more closely related to the number of feeding locations or pools than to their area. He speculated that the number of such feeding locations with suitable cover is more closely a function of stream length than area. Lister presented smolt yield data for five British Columbia streams, but excluded high gradient upper sections from estimates of stream length. The calculations revealed only small differences in yield per unit of stream length, and Lister concluded that 2,484 coho smolts per kilometer (4,000/mile) was a useful biostandard for determining smolt yield in streams.

Lister and Walker (1966) found that coho smolt production showed no increase at the Qualicum River Project on Vancouver Island for the two years of record following flow control implementation, despite increased egg-to-fry survival rates. Mundie (1969) concluded that the carrying capacity of the Qualicum had remained unchanged, since it was determined by the shallow marginal slack water areas representing the rearing space, and by the shallow riffle areas important for food production. He suggested that in this relatively large stream, the above areas were not increased by flow control.

Mundie (1969) compared coho rearing habitat in small streams with the habitat of the large Stamp River on Vancouver Island. He observed that coho fry in the Stamp River were distributed along margins and were unable to utilize the food or space in swift midstream waters. He noted that, compared to large streams, small or very small streams have the highest proportion of marginal slack water area to area of midstream. This relative proportion then, may be important in defining the carrying capacity of streams.

Edie (pers.comm. in Peterson MS 1980) established coho smolt yield levels for small tributaries of the Clearwater River in Oregon. He concluded that within the range of 125-625 smolts per kilometer, the number of smolts is influenced primarily by the size and gradient of the stream.

Mason (1974) was able to induce a six-fold increase in the summer standing crop of coho juveniles in experimental stream sections. He achieved this by augmenting the natural food supply with daily feedings of marine euphausiids. The result indicated that food supply is an important factor in determining carrying capacity. However, Mason subsequently found that the gain was nullified by winter freshets, as smolt yield the following spring approximated that expected from natural levels of production.

DATA SOURCES

The data compiled for this report, but not necessarily used in the analysis, included one or more years of recorded smolt outputs for 22 streams, 2 ponds, 2 side channels, 3 overwintering ponds and 2 lakes (Table 1). Of these data, one stream (Cowichan River), as well as all examples of overwintering ponds and lakes were excluded from the analysis of carrying capacity as they were not considered to be valid examples (see section on Categories of Coho Rearing Habitat).

Most of the data on rearing space and annual smolt yield were obtained from the literature. Additional data were obtained by personal communication with fisheries workers who supplied unpublished material. The search was fairly extensive and likely covered most of the pertinent material published, and perhaps most of the unpublished material available for British Columbia streams at the time of report writing. The integrity and limitations of the available data are discussed at the end of the report.

Appendix 1 lists for each stream, pond, etc., the detailed data on rearing space and annual smolt yield, as well as the numbers and biomass of coho per unit stream area and length. Table 1 provides a summary of the mean smolt yield values for each stream, pond, etc. for their respective years of record. Where complete data were available for a stream, pond, etc., smolt yield was given as both biomass (kg) and numbers, while rearing space was given as both length (km) and area (m^2). Annual smolt yields were identified as to smolt year (brood year was not considered appropriate because some streams produced both age 1+ and 2+ smolts).

CATEGORIES OF COHO REARING HABITAT

Streams, ponds, side channels, overwintering ponds and lakes were the five general categories of coho rearing habitat for which data were available. Each category is discussed below.

Table 1. Mean annual yield of coho smolts in numbers and biomass, and yield per unit area and length of stream.[a]

System[b,c]	Accessible portion Area (m^2)	Accessible portion Length (km)	Mean annual yield Numbers	Mean annual yield Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m2	Yield per length No./km	Yield per length kg/km	Years of data for Numbers	Years of data for Biomass
Stream/Pond/Side channel										
Needle Branch Creek	1,060	0.9	327	2.8	31	0.27	363	3.1	9	4
Bible Camp Side Channel	1,832	1.2	2,875	14.1	157	0.77	2,376	11.7	1	1
Cowichan Side Channel	2,508	0.8	2,202	15.1	88	0.60	2,686	18.5	2	2
Flynn Creek	2,660	1.3	863	8.3	32	0.32	663	6.4	9	4
Deer Creek	4,720	2.3	2,343	21.0	50	0.44	1,019	9.1	9	4
Hunts Creek, 1963-67	-	2.4	5,352	-	-	-	2,230	-	5	-
Meighn Creek	9,809	3.2	5,634	37.5	58	0.38	1,761	11.7	3	3
Pastuch Creek	10,037	3.3	3,819	25.2	38	0.25	1,157	7.6	2	2
Carnation Creek	-	3.5	2,130	-	-	-	614	-	4	-
Tenderfoot Creek & Pond	12,380	-	7,923	54.6	64	0.44	-	-	3	3
Little Stawamus River	12,409	3.7	6,659	39.2	54	0.32	1,800	10.6	2	2
Hooknose Creek	15,950	2.9	4,987	-	31	-	1,719	-	10	-
Miller Creek & Pond	17,125	-	5,369	72.5	31	0.42	-	-	1	1
Hunts Creek, 1971-74	-	5.2	6,867	57.4	-	-	1,321	11.0	4	1
Chef Creek	19,400	5.7	14,708	162.0	75	0.78	2,562	26.2	3	2
Nile Creek	25,600	5.6	4,973	-	19	-	888	-	8	-
Waddell Creek	-	10.3	6,445	-	-	-	626	-	4	-
Bonsall Creek	56,125	11.2	15,820	259.4	28	0.46	1,413	23.2	1	1
Kelvin Creek	56,931	11.4	13,980	139.8	25	0.25	1,224	12.2	1	1
Cheakamus River	-	15.1	38,667	-	-	-	2,561	-	1	-
Minter Creek	-	16.7	28,456	-	-	-	1,704	-	11	-
Salmon Creek	60,000	17.4	42,275	460.8	70	0.77	2,430	26.5	1	1
Qualicum River mainstem	197,400	10.5	31,693	408.0	17	0.20	3,018	38.9	7	2
Capilano River	-	23.3	56,410	-	-	-	2,421	-	2	-
Black Creek	-	30.6	46,191	707.0	-	-	1,510	23.1	2	1
Keogh River	-	35.0	65,000	690.0	-	-	1,857	19.7	3	2
* Cowichan River	-	55.2	152,951	-	-	-	2,771	-	1	-
Overwintering ponds										
* Clearwater R. spring pond # 1	8,498	-	3,613	42.6	43	0.50	-	-	1	1
* Clearwater R. spring pond # 2	12,869	-	1,534	29.6	12	0.23	-	-	1	1
* Rotary Park Ponds	13,561	-	14,850	137.4	110	1.01	-	-	2	2
Lakes										
* Mesachie Lake & Creek	589,975	-	53,309	591.7	9	0.10	-	-	1	1
* Cultus Lake	6,272,850	-	1,861	-	0.03	-	-	-	10	-

[a] Data were extracted from Appendix 1.
[b] Streams are listed in order of increasing size.
[c] Asterisk indicates that the system was excluded from the analysis.

STREAMS

The available data for streams covered a wide range of sizes from the very small Needle Branch Creek (0.9 km, 1,060 m^2) to the relatively large Qualicum River (10.5 km, 197,400 m^2) (Table 1). The range of productivities also varied widely from low yield streams such as Carnation Creek (614 smolts/km) to high yield streams such as Salmon River (2,430 smolts/km) (Table 1). The above variability in smolt production levels is probably associated mainly with differences in food production, but this variable was not investigated here.

Data for the relatively large Cowichan River system (Lister, pers. comm.), although listed in Appendix 1, were not considered for this analysis due to suspected low smolt production estimates. Specifically, Argue et al. (1979) found that smolt production in a small part of that system (Mesachie Creek and Lake) equalled almost a third of the system's total production as reported by Lister (Table 1).

PONDS

The data for two ponds and their associated creeks, Tenderfoot Creek and Pond (Argue and Armstrong 1977) and Miller Creek and Pond (Patterson et al. 1979), indicated that smolt production in ponds is comparable with that in streams on an area basis, but not on either a centreline or perimeter length basis. Because of the large area of the ponds relative to that of their outlet streams where traps were located, the ponds appeared to account for most of the rearing potential in these two small systems. This assumption was reinforced in the case of Tenderfoot Creek by the fact that the outlet stream dries most summers, and also dries occasionally at other times of the year during low rainfall periods.

Both Tenderfoot and Miller systems are utilized by coho spawners and their resultant juvenile progeny. Tenderfoot does not appear to be recruited by additional juveniles which may seek overwintering refuge but rear initially elsewhere in the parent system. The evidence for this came from a study where coho smolts captured in Tenderfoot Creek and marked with coded wire tags and adipose fin clips, were subsequently recovered as marked adults exclusively in the Tenderfoot system (Argue and Armstrong 1977). The exclusive homing suggested that non-native juveniles do not rear in the Tenderfoot system. This conclusion was based on the increasing evidence that coho spawners tend to return to the site of origin as emergent fry rather than to other sites where rearing and/or overwintering may have occurred.

Miller system, like the Tenderfoot, does not appear to have significant fall-winter recruitment since smolt densities there were comparable to smolt densities at the Tenderfoot.

SIDE CHANNELS

The data for Bible Camp and Cowichan side channels (Argue et al. 1979) revealed smolt yields which were numerically high in relation to channel length and area. However, the biomass yields did not exceed values reported for productive streams, such as Chef Creek (W.P. Wickett, pers. comm.) or Salmon River (R. Peterson, pers. comm.). Fall-winter recruitment to side channels may have accounted for some portion of the smolt yield, but this possibility did not warrant exclusion of the data in an analysis of stream carrying capacity. High production in natural groundwater-fed side channels may be attributed to moderate temperatures and stable flows, two features characteristic of such areas.

OVERWINTERING PONDS

Unlike the "ponds" category, overwintering ponds lack suitable spawning habitat, and therefore have no native coho fry populations. Consequently, data compiled for the overwintering ponds (Table 1) were excluded from the analysis of carrying capacity. These ponds are briefly discussed in the following paragraphs.

The one-year study of two spring-fed ponds which discharge into Clearwater River in Washington State, showed that production in the ponds was based almost entirely on fall-winter recruitment of juveniles which reared initially elsewhere in the system (Peterson MS 1980). Therefore, smolt production was not considered to be representative of the carrying capacity of these ponds, even though juveniles fed and grew there during the winter months.

Smolt yields for Rotary Park Ponds on the Cowichan River system (Argue et al. 1979) were well in excess of yields reported for other streams and ponds. Hence those ponds appeared to fit the category of overwintering ponds, and were also excluded from analysis.

LAKES

The data for the two lakes, Mesachie Lake (Argue et al. 1979) and Cultus Lake (Foerster and Ricker 1953), were excluded from this analysis since they were not comparable to the data for streams and ponds. If these two examples of lakes are indicative, smolt densities in lakes appear to be very low compared to streams and ponds (Table 1). Nevertheless, Mesachie may rank among productive lakes, producing an estimated 53,309 smolts at a density of 9 fish/100 m^2 in the smolt year 1976 (Table 1). By contrast, the much larger Cultus Lake produced an average of only 1,861 smolts at a density of 0.03 fish/100 m^2 during the 10 years of record (Table 1). Cultus Lake also showed wide variations in the annual densities (Appendix 1). The data for both lakes were clouded by unknown, but probably minor, smolt contributions from small tributaries entering the lakes. In addition, evidence presented for Cultus Lake by Foerster and Ricker (1953) indicated that coho smolt production in lakes may be largely determined by population levels of fish predators.

ANALYSIS OF THE DATA

RELATIONSHIP BETWEEN VARIABLES

In the present analysis, data were included for 21 streams, 2 ponds and 2 side channels; data were excluded for the Cowichan River, all overwintering ponds and the two lakes (Table 1). The two smolt yield variables (numbers and kilograms) were compared with the two rearing space variables (stream area and length) by applying two tests. Testing for linear relationship was carried out by applying the equation:

$$y = a + bx.$$

Testing for a curvilinear relationship was carried out by applying the equation:

$$y = ax^b$$

In both equations, y represents smolt yield in numbers or kilograms, x represents rearing space in kilometers or square meters, while a and b are the constants determining the line or curve. The two tests were applied to the following three data groupings:

1. Streams for which data on all four variables were available.
2. Small streams less than 4 km in length or 20,000 m^2 in area.
3. Streams of all sizes.

(Note: The term "stream" in this and the following sections includes streams, ponds and side channels, unless otherwise stated).

Table 2 shows the goodness of fit (r) for the two statistical tests applied to the three data groupings.

Table 2. Test for goodness of fit (r) of the linear ($y = a + bx$) and curvilinear ($y = ax^b$) equations in comparative tests of the data on smolt yields (numbers and biomass) and rearing space (stream area and length).

			r Values			
			Area		Length	
Data grouping	Sample size	Equation	Numbers	Biomass	Numbers	Biomass
Stream with complete data	13	$y=a+bx$	0.82	0.87	0.94	0.95
		$y=ax^b$	0.92	0.95	0.90	0.94
Small streams*	8-11	$y=a+bx$	0.79	0.95	0.70	0.91
		$y=ax^b$	0.85	0.93	0.70	0.80
Streams of all sizes	15-24	$y=a+bx$	0.74	0.80	0.94	0.96
		$y=ax^b$	0.91	0.96	0.92	0.96

* Less than 4 km in length or 20,000 m^2 in area.

High r values (≥ 0.70) were obtained in all comparative tests of the four variables, and the r values were significant at the 95% confidence level ($p \leq 0.05$). The above analysis indicates that any combination of the two smolt yield variables with the two rearing space variables is representative of the carrying capacity, and that both equations are adept in describing the relationships.

However, while the individual r values are significant (ie., are significantly different from zero), the differences between them are not. This is due to small sample sizes and the nearly equal performance of the variables. As a result, we could not demonstrate conclusively in this analysis that smolt biomass is superior or inferior to numbers as a measure of carrying capacity. Similarly, we could not show that stream area is superior or inferior to stream length in that regard, or that one statistical test is superior to the other. Clearly, however, all four variables provide a good measure of the carrying capacity of streams.

Despite the limitations imposed by mathematical discipline, there were small but consistent differences in the r values which suggested certain trends or tendencies in the data. The following trends were considered worthy of speculation.

Linear vs. Curvilinear Relationship

The r values in Table 2 show that on the basis of smolt yield per area, the best fit of the data is to the curve $y = ax^b$, while on the per length basis the best fit, but only slightly so, is to the linear equation $y = a + bx$. An inherent shortcoming of the linear equation is that it describes a simple mean relationship for all the data analyzed; hence it does not accommodate what appear to be variations from the mean at both ends of the data spread. As a result, the linear equation tends to overstate production for the smaller streams and understate production for the larger streams. This anomaly is seen in Figures 1 to 4 where the two linear regression types are graphed.

On this basis, therefore, the curve $y = ax^b$ is considered to be superior to the linear equation in describing stream carrying capacity. This is true particularly on an area basis, but also on a length basis because of improved accuracy with regard to upper and lower extremes of stream size.

Biomass vs. Numbers

Table 2 shows that in comparative tests of smolt yield, r values are consistently higher for biomass than numbers, although in several instances the differences are small. This observation applies to both equations. On this basis we conclude that biomass is superior to numbers as an expression of stream carrying capacity.

Area vs. Length

For the data grouping of small streams (<4 km or < 20,000 m^2), r values using either equation are higher when comparing yield per area than yield per length (Table 2). Thus, area is considered to be superior to length as an expression of carrying capacity for small streams. However, for streams with complete data (these included a few larger streams) and for streams of all sizes, length is the superior variable for the linear equation, while both length and area are equally representative for the curvilinear equation (Table 2). These observations are summarized below:

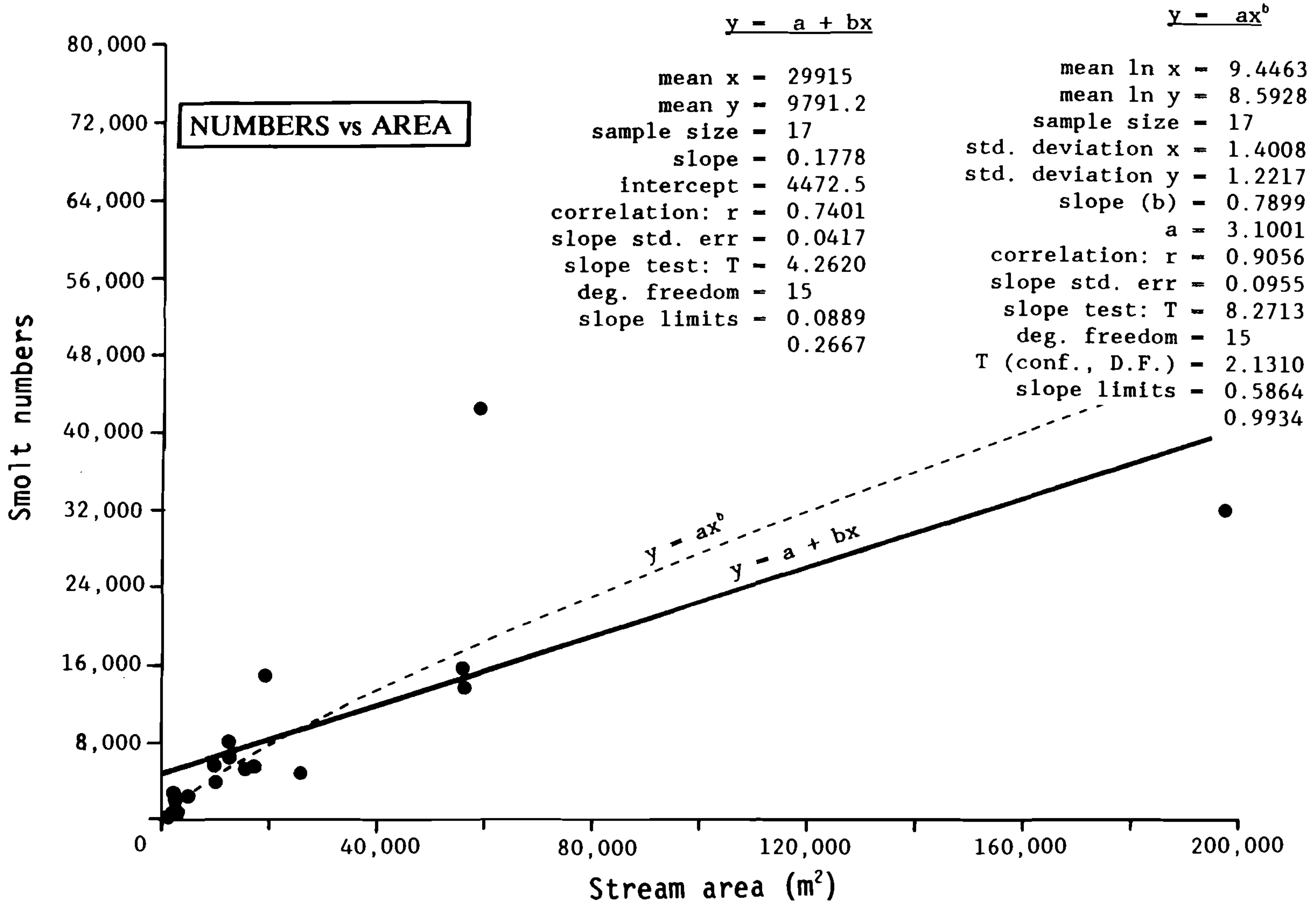

Fig. 1. Relationship between coho smolt yield as numbers, and rearing space as accessible stream area (m^2), for streams of all sizes.

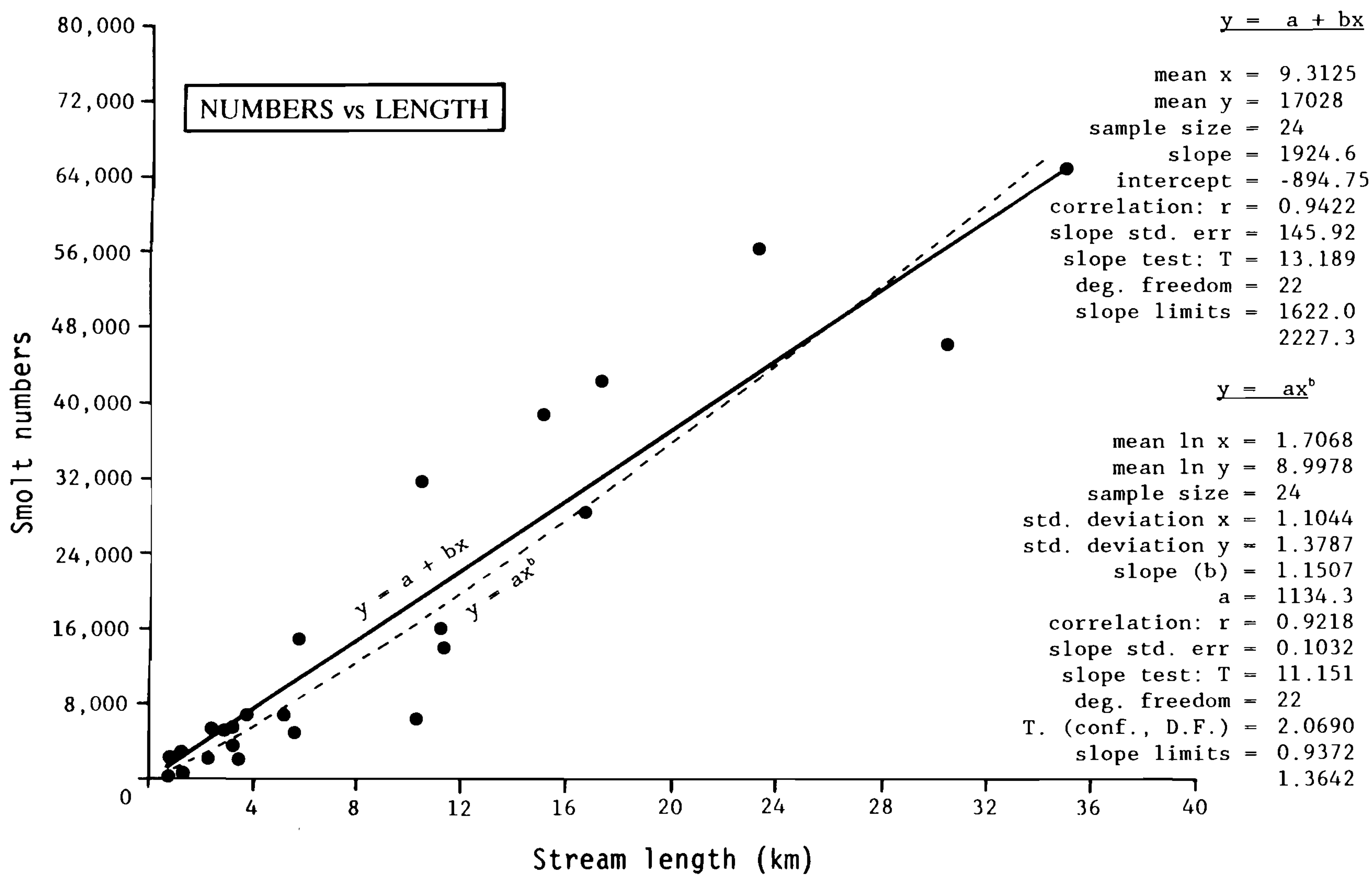

Fig. 2. Relationship between coho smolt yield as numbers, and rearing space as accessible stream length (km), for streams of all sizes.

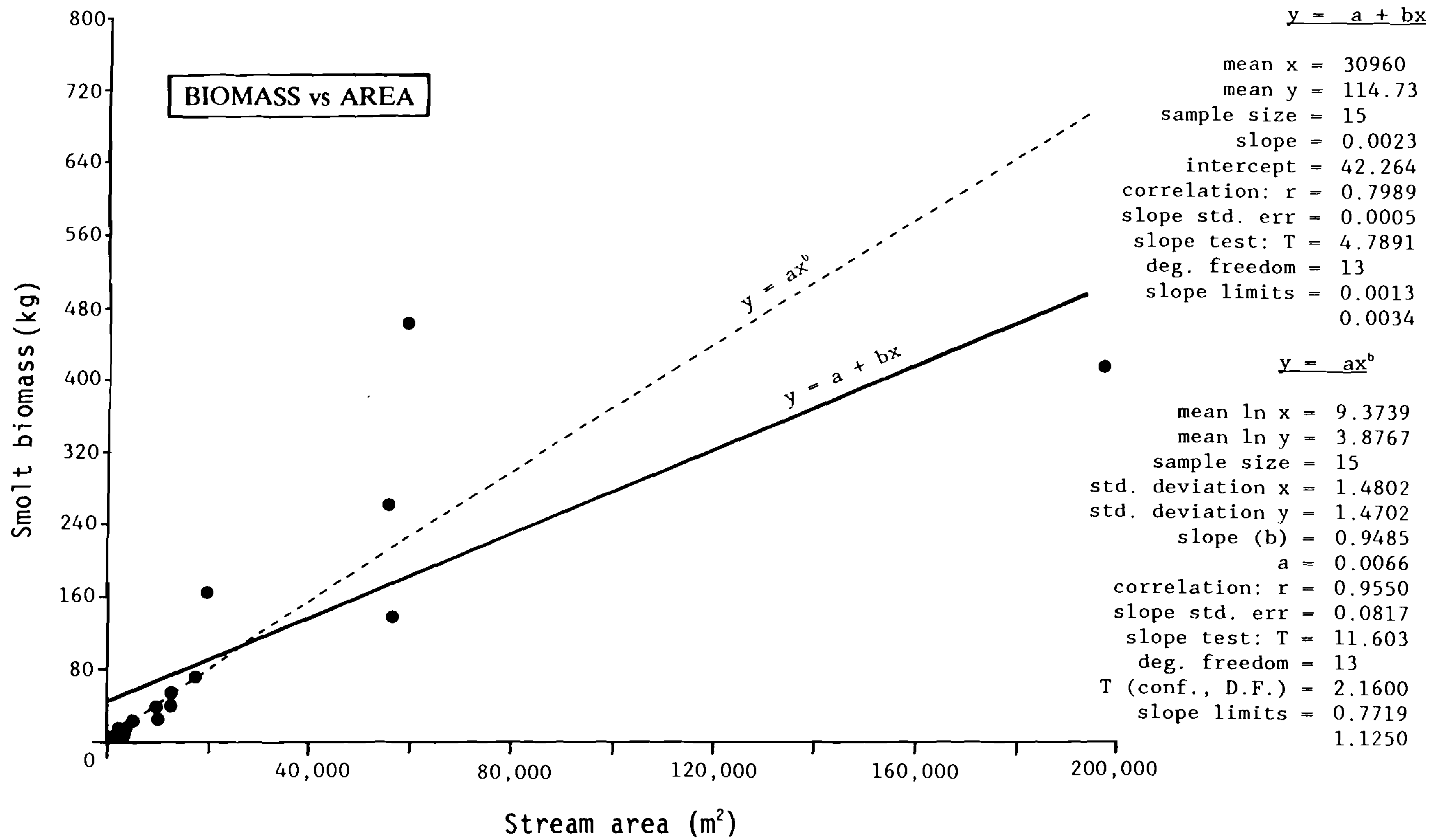

Fig. 3. Relationship between coho smolt yield as biomass (kg), and rearing space as accessible stream area (m^2), for streams of all sizes.

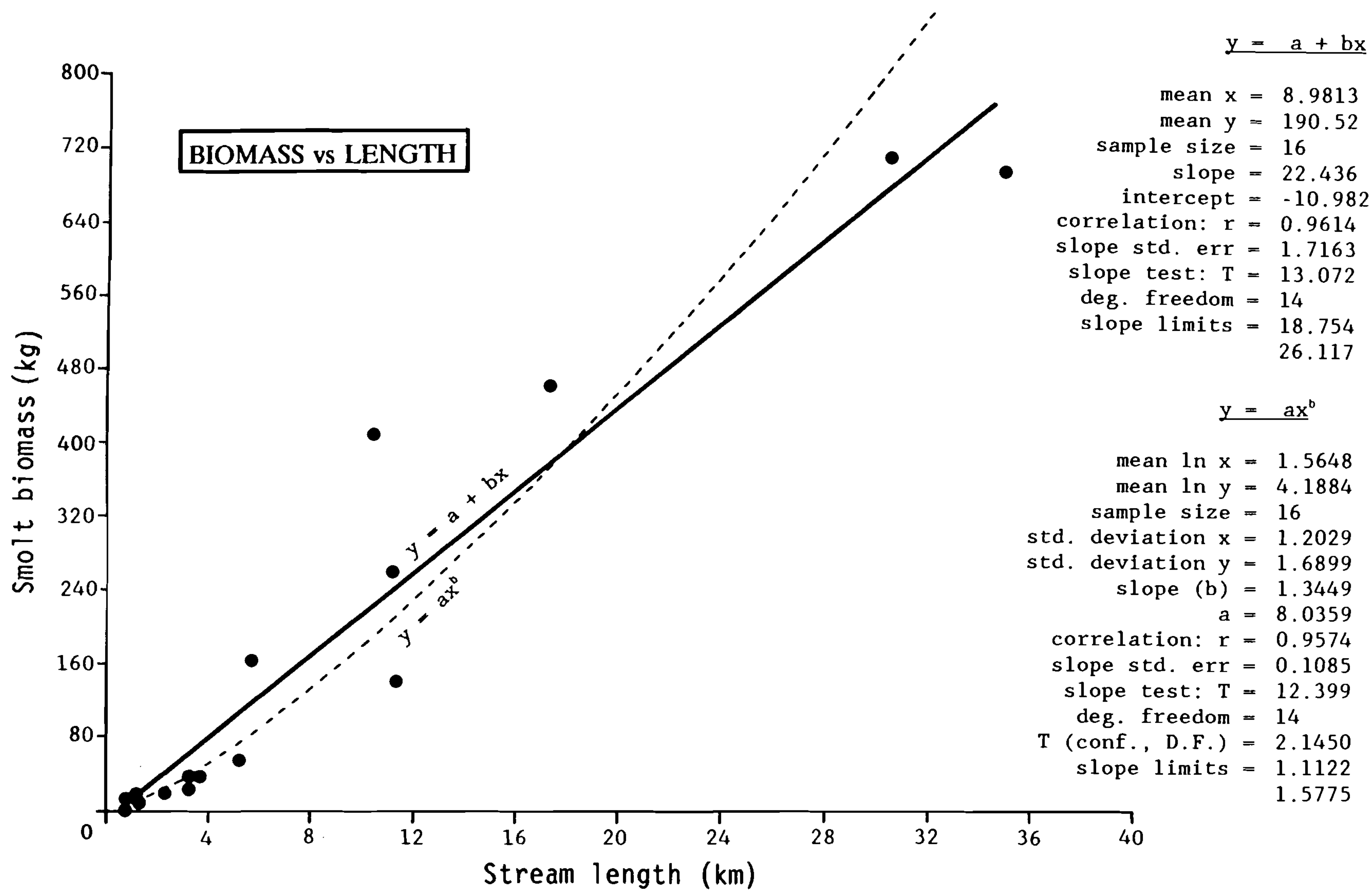

Fig. 4. Relationship between coho smolt yield as biomass (kg), and rearing space as accessible stream length (km), for streams of all sizes.

Data grouping	The superior variable for expressing carrying capacity: $y = a+bx$	$y = ax^b$
Small streams	Area	Area
Streams with complete data	Length	Length and area
Streams of all sizes	Length	Length and area

Our findings generally agree with earlier studies. For example, Chapman (1965) and Burns (1971) concluded that smolt biomass and stream area were the two variables that most closely described stream carrying capacity. The studies on which their findings were based were carried out on small streams. The present analysis supports their contention with respect to biomass, and also with respect to stream area in the case of small streams.

Lister (MS 1968b) proposed that smolt yield was more closely a function of stream length than area. His contention was based on finding similar smolt production per unit length for streams of quite different sizes. The present analysis supports his contention if a linear relationship between smolt yield and the two rearing space variables is assumed. However, with the use of the curvilinear equation, either of the rearing space variables is valid for streams of all sizes.

CALCULATION OF MEAN CARRYING CAPACITY FOR STREAMS OF VARIOUS SIZES

In developing equations for calculating mean carrying capacity for streams of various sizes, we used the data in Table 1 for streams of all sizes. Calculations were based on the curvilinear equation $y = ax^b$. Constants a and b were calculated for each of the four combinations of smolt yield and rearing space variables:

Combination tested*	Constants a	b
Numbers vs. area	3.1001	0.7899
Numbers vs. length	1134.3	1.1507
Biomass vs. area	0.0066	0.9485
Biomass vs. length	8.0359	1.3449

* Units: biomass (kg), area (m^2), length (km).

By applying to the equation $y = ax^b$, any given value of stream length or area, and the appropriate values for the constants a and b shown above, the mean annual smolt yield in numbers or biomass could be calculated for that given size of stream. This exercise was conducted for hypothetical streams of various sizes (Table 3).

Table 3. Mean total annual yield of coho smolts in numbers and biomass, yield per unit area and length of stream, and mean smolt size calculated for streams of various sizes.*

Stream area (m^2)	Smolt yield by area: Total No.	Total kg	Per 100 m^2 No.	Per 100 m^2 kg	Mean smolt size (g)	Stream length (km)	Smolt yield by length: Total No.	Total kg	Per km No.	Per km kg	Mean smolt size(g)
1,000	726	4.6	73	0.46	6.3	0.5	511	3.2	1,022	6.4	6.3
2,000	1,256	8.9	63	0.44	7.1	1	1,134	8.0	1,134	8.0	7.1
5,000	2,589	21.2	52	0.42	8.2	2	2,518	20.4	1,259	10.2	8.1
10,000	4,477	41.1	45	0.41	9.2	3	4,016	35.2	1,339	11.7	8.8
15,000	6,167	60.3	41	0.40	9.8	4	5,591	51.8	1,398	13.0	9.3
25,000	9,232	97.9	37	0.39	10.6	5	7,228	70.0	1,446	14.0	9.7
50,000	15,962	189.0	32	0.38	11.8	10	16,048	177.8	1,605	17.8	11.1
100,000	27,598	364.8	28	0.36	13.2	20	35,630	451.6	1,782	22.6	12.7
200,000	47,715	704.0	24	0.35	14.8	30	56,812	779.1	1,894	26.0	13.7

* Calculations were based on the equation $y = ax^b$ for values of a and b derived from the data in Table 1.

Table 3 shows considerable differences in the mean annual smolt yield per unit stream area or length, calculated for a very small stream compared to a large stream:

		Smolt yield/100 m^2		Smolt yield/km	
		No.	kg	No.	kg
Small stream	(1,000 m^2 or 0.5 km)	73	0.46	1,022	6.4
Large stream	(200,000 m^2 or 30 km)	24	0.35	1,894	26.0

From the above examples and other values given in Table 3, three noteworthy trends can be seen in the data related to carrying capacity:

(a) Smolt yield (numbers or biomass) decreases per unit area with increasing area of stream.

(b) Smolt yield (numbers or biomass) increases per unit length with increasing length of stream.

(c) The mean weight of smolts increases with increasing size (length and area) of stream.

Rephrasing the above in ordinary terms: large streams tend to be more productive per unit length than small streams but less productive per unit area, and large streams tend to produce bigger smolts than small streams.

Small streams, therefore, are the most efficient producers of smolts if production per unit area is the criterion for efficiency. This also implies greater efficiency with respect to volume of stream flow. On the other hand, large streams may show improved efficiency relative to small streams, if the smolt-to-adult survival rate of coho is directly related to smolt size.

The three trends mentioned above, may be the result of a number of ecological factors associated with differences in quality and quantity of rearing habitats in large and small streams. However, one factor stands out prominently that tempts speculation;that is, that carrying capacity, expressed as smolt yield per length or area of stream, involves a third rearing space variable - stream width. The suggested functional relationship of this concept is shown graphically in Figures 5 and 6.

The concept is explained as follows. Studies show that rearing coho juveniles occupy stream margins (Mundie 1969), progressing to deeper and swifter waters as growth and development proceeds (Lister and Genoe 1970). Thus, it could be expected that in small and hence narrow streams a conflict of overlapping foraging territories would develop in time between fish occupying left and right bank stations. Such a conflict would probably inhibit fish growth or encourage emigration, or both. This would explain lower productivity per unit stream length (Fig. 5) and smaller smolt size for small streams (Table 3). In contrast, in larger and consequently wider streams the conflict of overlapping territories would diminish as stream width increases, being avoided entirely at

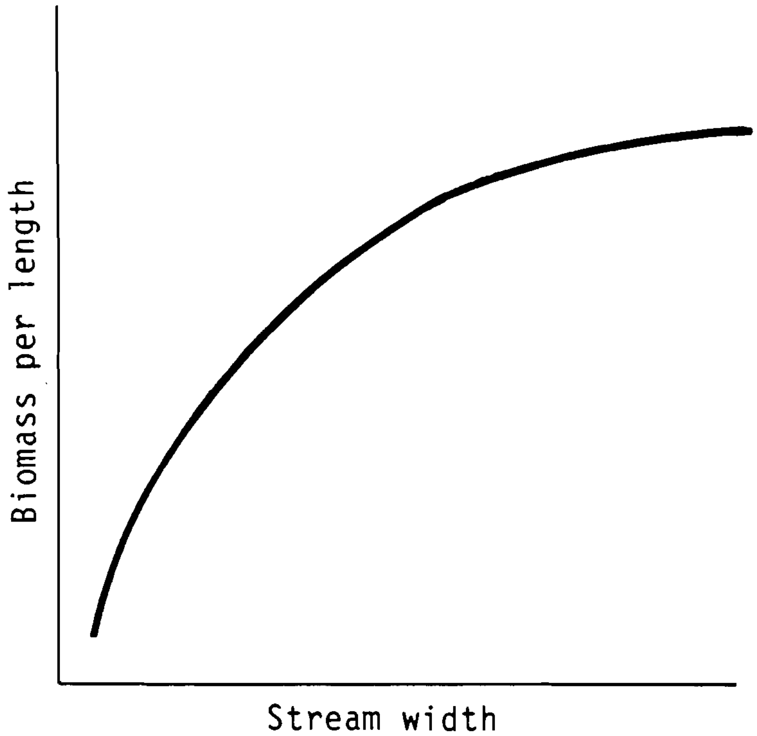

Fig. 5. Hypothetical relationship between coho smolt yield (biomass per unit stream length) and stream width.

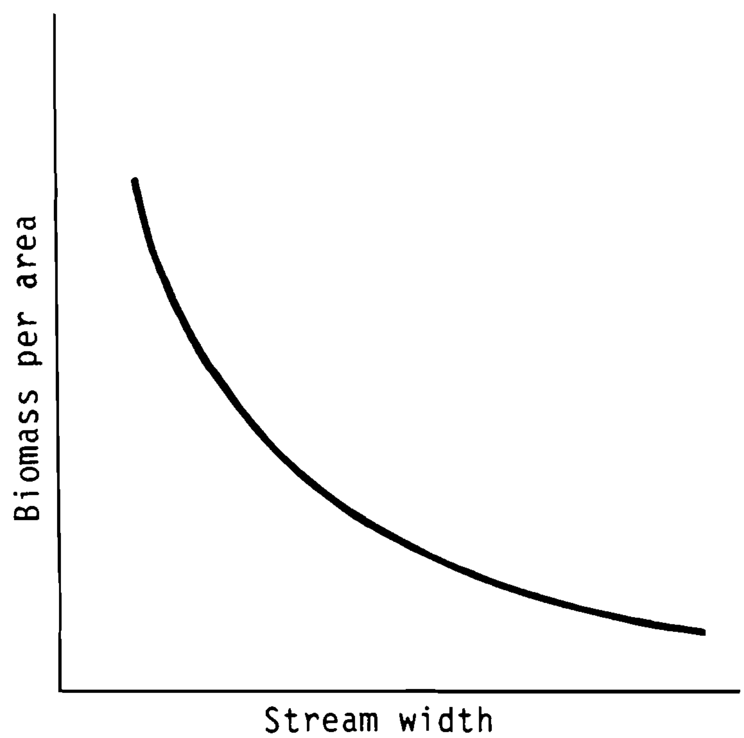

Fig. 6. Hypothetical relationship between coho smolt yield (biomass per unit stream area) and stream width.

some critical stream width. In such large streams, the wider uncontested water column where juveniles could forage would result in increased population densities per unit stream length, as well as uninhibited fish growth. However, with increasing stream width the efficiency of foraging would likely diminish so that the entire central water column of very large rivers would be unutilized. This would explain the observation of lower production per unit area with increasing size (width) of stream (Fig. 6).

INTEGRITY AND LIMITATIONS OF THE DATA SOURCES

Probably the best data used for this analysis, in terms of both quantity and quality, came from Chapman (1965). He documented the carrying capacities of three small Oregon streams over the first four years of an intensive study involving a pre-and post-logging assessment. Chapman provided all pertinent information on parr and smolt yields, as well as on rearing space dimensions recorded at the time of minimum flows. Hall and Lantz (1969) reported on an additional five years of the study, but unfortunately did not provide information on smolt output measured as biomass.

While all the sources provided numerical smolt yield data, several were deficient in the other three variables: biomass, stream length and stream area. Sometimes the missing information was extracted from other literature sources, such as Wickett and Ballantyne (1976), or by personal communication. All such incidental information sources are listed in Appendix 1.

Some of the Appendix 1 data on mean weight, biomass and smolt density were extrapolations. For example, for Black Creek on Vancouver Island, Clark (MS 1978) provided only smolt numbers and their mean weight. We multiplied the two values to obtain biomass, and used the Black Creek length data from Hamilton (1978) to calculate smolt density in numbers and kilograms per kilometer of stream.

Of the four variables used to describe stream carrying capacity (ie. smolt numbers and biomass, stream length and area), the latter two and particularly stream area, appeared to be the least reliable for quantifying carrying capacity. For example, Chapman (1965) reported on smolt densities, based on minimum rearing space, for three small Oregon streams. The rearing space was based on stream length and area recorded during the lowest stream flow in the year preceding smolt migration. By comparison, Argue and Armstrong (1977), Argue et al. (1979) and Patterson et al. (1979), measured rearing space in the spring at the time of smolt migration, which is normally a period of moderate flows (R. Armstrong, pers. comm.). Similarly Hunter (1959) provided 10 years of smolt output data for Hooknose Creek, as well as stream length and other physical description of the watershed. However, in calculating the rearing area for our analysis, we excluded the 2.6 km-long Port John Lake in the headwaters. Our decision was based on a brief statement by Hunter that smolts were not captured in the trap installed near the lake outlet on one occasion during a spring migration period.

Most of the studies reported in the literature for which smolt data were obtained, involved small or very small streams. The Qualicum River provided the only good information source for a relatively large stream, although it was not considered to be a typical example because of the stabilizing influence of flow control. However, as mentioned previously, Lister and Walker (1966) found no increase in the level of coho smolt production for the two years of record following flow control implementation. Subsequent studies of this stream (Paine et al. 1975; Sandercock and Minaker 1975), also indicated no change in the level of annual smolt output, except for one aberrant year when the output doubled.

Mention should be made of the validity (but not necessarily the accuracy) of three other data sources (ie. Minter Creek, Waddell Creek and Hunts Creek) which although included in the analysis, may not represent typical coho salmon streams. These data were included since no compelling reason existed for rejecting them. Each source is discussed below.

Minter Creek, Washington (Salo and Bayliff 1958): Numbers of coho females spawning naturally in the creek above the weir were controlled by hatchery personnel. Experimentation with a very low spawning density in the brood year 1948 may have resulted in the unusually low smolt production reported for this stream in 1950. Additionally, from 1938 onward, displaced "surplus" fry were not allowed to leave the stream during the spring following emergence. Instead, fry caught in downstream traps were returned above the weir. This measure was considered necessary as the weir prevented the upstream passage of fry that might otherwise return. However, such interference with natural regulation of juvenile rearing densities may have influenced smolt output.

Waddell Creek, California (Shapovalov and Taft 1954): The highest and lowest numerical smolt yields for the four years of record for this stream revealed an almost 7-fold difference. This was in contrast to the more uniform annual production demonstrated by the more northerly streams. Moreover, even the highest annual production appeared to be low for a stream of this size. It is suggested that some environmental factors may be operating at Waddell Creek which tend to inhibit coho production near the species' southern limit of distribution along the Pacific Coast.

Hunts Creek, British Columbia (Paine et al. 1975): During 1971 to 1973, smolt yield from this tributary of the Qualicum River on Vancouver Island, was the progeny of both wild and hatchery outplanted fry. Appendix 1 shows the numbers planted over the three-year period. As in the case of Minter Creek, interference with natural mechanisms controlling population density, may have influenced smolt yields. One notable change was an increase in the proportion of age 2+ smolts among migrants during the hatchery outplant period.

Among the data collected, an unfortunate information gap was noted regarding streams in northern regions (ie., Alaska and northern British Columbia) and streams remote from tidewater (eg., up-river tributaries of the Skeena, Fraser and Columbia rivers). Both these areas may differ in levels of productivity from the coastal streams located in the southern half of the coho distribution range.

No useful quantitative information was found in the literature on smolt yields resulting from colonization of streams, ponds, lakes or reservoirs. The Washington Department of Fisheries reported on a fairly extensive stocking program in lakes and ponds in the 1950s and 1960s using hatchery coho fry. However, due to the inherent difficulties in assessing such a program, no smolt yield data were given. In any case, such data would probably be unsuitable for an analysis of natural carrying capacity because most stocking projects were preceded by extensive measures of predator control, such as the removal of coarse fish with piscicides.

In British Columbia, only a few coho colonization projects have been documented. Lister (MS 1968a) introduced a mixture of hatchery-incubated and wild coho fry into Woodhus Creek, a tributary of the Oyster River on Vancouver Island. Fry were released above a waterfall which prevented natural colonization. However, while Lister obtained comparative fry-to-smolt survival rates, he presented no data on stream length or area. Other workers introduced coho fry into other Vancouver Island streams, including Shawnigan Creek, Bevan Creek (Puntledge River tributary), Koksilah River and Chemainus River. Again, for two of these streams (Shawnigan and Bevan) where smolt yields were assessed, no information was given on stream size.

Some studies of stream carrying capacity were based on late summer standing crops of juvenile salmonids, with assessments made at the time of least rearing space, or shortly thereafter (eg., Burns 1971). Stream assessment work carried out by the Fish Habitat Improvement Section of the British Columbia Fish and Wildlife Branch also uses this approach to determine and compare productivities (R. Ptolemy pers.comm.). However, while the technique is a measure of carrying capacity according to the definition of Burns (1971), it does not account for subsequent growth of juveniles to the time of smoltification. Nor does it account for overwinter mortality which can reduce numbers by as much as 65% (Bustard and Narver 1975; Peterson MS 1980). Therefore, data based on late summer standing crops of coho juveniles were not utilized in this report.

CONCLUSIONS

The smolt yield equations developed in this report may find useful application in fishery management involving natural production of coho. For example, predictions can be made of production levels and associated economic benefits that can be realized from various stream enhancement activities. Such activities may include colonization, either by removal of obstructions or by the annual release of fry above them; other activities may involve stream improvement work, such as the construction of rearing ponds and channels.

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REFERENCES

Andersen, B.C. and D.W. Narver. 1975. Fish populations of Carnation Creek and other Barkley Sound streams - 1974: Data record and progress report. Fish. Res. Bd. Can. MS Rep. 1351 : 73 p.

Argue, A.W. and R.W. Armstrong. 1977. Coho smolt coded-wire tagging and enumeration (1971 to 1973 broods) on three small tributaries in the Squamish River system. Fish. Mar. Ser. Data Rep. PAC/D-77-11 : 79 p.

Argue, A.W., L.M. Patterson and R.W. Armstrong. 1979. Trapping and coded-wire tagging of wild coho, chinook and steelhead juveniles from the Cowichan-Koksilah River system, 1976. Fish. Mar. Ser. Tech. Rep. 850 : 117 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.

Bustard, D.R. and D.W. Narver. 1975. Aspects of the winter ecology of juvenile coho salmon (Oncorhynchus kisutch) and steelhead trout (Salmo gairdneri). J. Fish. Res. Bd. Can. 32 : 667-680.

Clark, D.G. MS 1978. Enumeration and coded-wire tagging of coho smolts, Black Creek, 1978. Fish. Mar. Ser., Vancouver, B.C. MS Rep. on File No. 5903-85-B161 : 21 p.

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

de Hrussoczy-Wirth, V.C. 1979. Coded-wire tagging of wild coho juveniles from the Keogh River system, 1977 and 1978. Fish. Mar. Ser. MS Rep. 1506 : 25 p.

Foerster, R.E. and W.E. Ricker. 1953. The coho salmon of Cultus Lake and Sweltzer Creek. J. Fish. Res. Bd. Can. 10 : 293-319.

Hall, J.D. and R.L. Lantz. 1969. Effects of logging on the habitat of coho salmon and cutthroat trout in coastal streams. In T.G. Northcote (ed). Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheries. Univ. British Columbia, Vancouver. 355-375.

Hamilton, R.E. 1978. Black Creek, Vancouver Island, B.C. hydrology, fisheries resource, and watershed development. Fish. Mar. Ser. MS Rep. 1484 : 35 p.

Hunter, J.G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Bd. Can. 16 : 835-886.

Le Chasseur, A.J. MS 1979. Enumeration of coho smolts, Black Creek, 1979. Fish. Mar. Ser. MS Rep. on File No. 5903-85-B161 : 10 p.

Lister, D.B. MS 1968a. Progress brief on the coho transplant study at Woodhus Creek, Vancouver Island. MS Rep. 16 p.

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

Lister, D.B. and C.E. Walker. 1966. The effect of flow control on freshwater survival of chum, coho and chinook salmon in the Big Qualicum River. Can. Fish Culturist. 37 : 3-25.

Lister, D.B. and H.S. Genoe. 1970. Stream habitat utilization by cohabiting underyearlings of chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon in the Big Qualicum River, British Columbia. J. Fish. Res. Bd. Can. 27 : 1215-1224.

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

Mundie, J.H. 1969. Ecological implications of the diet of juvenile coho in streams. In T.G. Northcote (ed.). Symposium on salmon and trout in streams. H.R. MacMillan Lectures in Fisheies. Univ. British Columbia, Vancouver. 135-152.

Narver, D.W. and B.C. Andersen. 1974. Fish populations of Carnation Creek and other Barkley Sound streams - 1970-1973: Data record and progress report. Fish. Res. Bd. Can. MS Rep. 1303 : 115 p.

Paine, J.R., F.K. Sandercock and B.A. Minaker. 1975. Big Qualicum River project, 1972-1973. Fish. Mar. Ser. Tech. Rep. PAC/T-75-15 : 126 p.

Patterson, L.M., M.A. Erickson and V.C. de Hrussoczy-Wirth. 1979. Trapping and coded-wire tagging of wild coho and steelhead juveniles from the Chemainus River system, 1977 and 1978. Fish. Mar. Ser. MS Rep. 1507 : 32 p.

Pearlstone, P.S.M. 1976. Management implications of summer habitat characteristics of juvenile steelhead trout (Salmo gairdneri) in the Big Qualicum River. Fish. Management Rep. No. 67. Min. Env., Fish and Wildlife Br. 13 p.

Peterson, N.P. MS 1980. The role of spring ponds in the winter ecology and natural production of coho salmon (Oncorhynchus kisutch) on the Olympic Peninsula, Washington. MS Thesis. Univ. Wash. 96 p.

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.

Sandercock, F.K. and B.A. Minaker. 1975. Big Qualicum River project, 1973-1974. Fish. Mar. Ser. Tech. Rep. PAC/T-75-16 : 120 p.

Shapovalov, L. and A.C. Taft. 1954. The life histories of the steelhead trout (S. gairdneri) and silver salmon (O. kisutch) with special reference to Waddell Creek, California. Calif. Dept. Fish and Game, Fish. Bull. No. 98 : 375 p.

Wickett, W.P. 1951. The coho salmon population of Nile Creek. Fish. Res. Bd. Can., Progr. Repts. Pac. Coast Stations, No. 89 : 88-89.

Wickett, W.P. and A. Ballantyne. 1976. Area of pink and chum salmon spawning grounds in British Columbia and density of spawners, 1951-1955. Fish. Mar. Ser. Data Rep. No. 10 : 143 p.

Appendix 1. Annual yield of coho smolts in numbers and biomass, and annual yield per unit area and length of stream. (Data are for various Pacific coast streams, ponds, side channels, overwintering ponds and lakes obtained form the literature).

Reference	Stream	Accessible portion Area (m^2)	Accessible portion Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m^2	Yield per length No./km	Yield per length kg/km
Chapman (1965)[1]	D.W.Deer Creek,	-	2.3	1960	1,680	-	-	36	-	730	-
	Alsea River,	4,753		1961	3,169	7.2	22.8	67	0.48	1,378	9.9
	Oregon	4,753		1962	1,919	9.0	17.3	40	0.36	834	7.5
		4,720		1963	2,298	7.6	17.5	49	0.37	999	7.6
		4,720		1964	2,762	9.5	26.2	59	0.56	1,201	11.4
					2,366	8.3	21.0	50	0.44	1,028	9.1
	Flynn Creek,	2,459	1.3	1961	1,281	7.1	9.1	52	0.37	985	7.0
	Alsea River,	2,760		1962	872	9.1	7.9	32	0.29	671	6.1
	Oregon	2,657		1963	757	8.6	6.5	28	0.24	582	5.0
		2,657		1964	1,356	7.3	9.9	51	0.37	1,043	7.6
					1,066	8.0	8.3	41	0.32	820	6.4
	Needle Branch	926	0.9	1961	200	9.1	1.8	22	0.19	222	2.0
	Creek, Alsea	1,114		1962	471	7.9	3.7	42	0.33	523	4.1
	River, Oregon	1,060		1963	191	8.3	1.6	18	0.15	212	1.8
		1,060		1964	550	7.5	4.1	52	0.39	611	4.6
					353	8.2	2.8	34	0.27	392	3.1

[1] Pre (1960-67) and post-logging (1968-69) studies: Needle Branch Creek was clear cut; Deer Creek was patch-logged; Flynn Creek was not logged and served as a control stream. Smolt numbers include all emigrants, excluding fry, for the period November 1 to July 1.

Appendix 1 (Cont'd).

Reference	Stream	Accessible portion Area (m^2)	Accessible portion Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m^2	Yield per length No./km	Yield per length kg/km
Hall and Lantz (1969)[1]	Deer Creek, Alsea River, Oregon	4,720	2.3	mean 61-67	2,339	-	-	50	-	1,017	-
				1968	2,252	-	-	48	-	979	-
				1969	2,460	-	-	52	-	1,070	-
				mean 61-69	2,460	-	-	50	-	1,019	-
	Flynn Creek, Alsea River, Oregon	2,660	1.3	mean 61-67	882	-	-	33	-	678	-
				1968	969	-	-	36	-	745	-
				1969	622	-	-	23	-	478	-
				mean 61-69	863	-	-	32	-	663	-
	Needle Branch Creek, Alsea River, Oregon	1,060	0.9	mean 61-67	334	-	-	32	-	371	-
				1968	327	-	-	31	-	363	-
				1969	276	-	-	26	-	307	-
				mean 61-69	327	-	-	31	-	363	-
de Hrussoczy-Wirth (1979) P.A. Slaney (pers. comm.)	Keogh River		35[2]	1977	63,000	12	756.0	-	-	1,800	21.6
				1978	52,000	12	624.0	-	-	1,486	17.8
				1979	80,000	-	-	-	-	2,286	-
					65,000	12	690.0	-	-	1,857	19.7

[2] Stream length (35 km) does not include tributaries (P.A. Slaney, pers. comm.).

Appendix 1 (Cont'd).

Reference	Stream	Accessible portion Area (m^2)	Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	kg/100 m^2	Yield per length No./km	kg/km
Salo and Bayliff (1958)	Minter Creek, Washington	-	16.7[3]	1940	35,452	-	-	-	-	2,123	-
				1942	32,085	-	-	-	-	1,921	-
				1944	31,893	-	-	-	-	1,910	-
				1945	23,177	-	-	-	-	1,388	-
				1946	30,408	-	-	-	-	1,821	-
				1948	41,848	-	-	-	-	2,506	-
				1950[4]	17,839	-	-	-	-	1,068	-
				1951	27,781	-	-	-	-	1,664	-
				1953	22,545	-	-	-	-	1,350	-
				1954	31,363	-	-	-	-	1,878	-
				1955[4]	18,620	-	-	-	-	1,115	-
					28,456	-	-	-	-	1,704	-
Shapovalov and Taft (1954)	Waddell Creek, California	-	10.3	1935	8,389	-	-	-	-	814	-
				1936	11,331	-	-	-	-	1,100	-
				1937	1,684	-	-	-	-	163	-
				1938	4,377	-	-	-	-	425	-
					6,445	-	-	-	-	626	-

[3] Length (16.7 km) does not include Murray Creek (5.03 km), a tributary reported to dry up each summer.

[4] Smolt yield in 1950 low, probably the result of very low spawning density in 1948. Smolt yield in 1955 low, possibly the result of a late-season transplant of hatchery fingerlings superimposed on wild stock.

Appendix 1 (Cont'd).

Reference	Stream	Accessible portion Area (m^2)	Accessible portion Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m^2	Yield per length No./km	Yield per length kg/km
Lister and	Qualicum system	-	12.9	1961	30,600	-	-	-	-	2,372	-
Walker (1966)				1962	26,000	-	-	-	-	2,016	-
D.B. Lister				1963	34,300	-	-	-	-	2,659	-
(pers. comm.)				1964	33,400	-	-	-	-	2,589	-
				1965	34,700	-	-	-	-	2,690	-
				1966	26,800	-	-	-	-	2,078	-
				1967	28,600	-	-	-	-	2,217	-
					30,629	-	-	-	-	2,374	-
Lister, and	Qualicum mainstem	147,000[5]	10.5	1963	28,100	-	-	19	-	2,676	-
Walker (1966)				1964	27,900	-	-	19	-	2,657	-
Paine et al. (1975)		197,400[6]		1965	30,300	-	-	15	-	2,886	-
Sandercock and				1966	21,000	-	-	11	-	2,000	-
Minaker (1975)				1967	23,600	-	-	12	-	2,248	-
				1973	61,464	8.0	491.7	31	0.25	5,854	46.8
				1974	29,485	11.0[7]	324.3	15	0.16	2,808	30.9
					31,693	9.5	408.0	17	0.20	3,018	38.9

5 Area (147,000 m^2) back calculated from Lister's report of approximately 19 smolts/100 m^2 in 1963 & 1964.
6 Area (197,400 m^2) given in Pearlstone (1976) for period after flow control.
7 Mean weight of 11.0 g based on a sample of 200 fish collected over 5 consecutive days.

Appendix 1 (Cont'd).

Reference	Stream	Accessible portion Area (m^2)	Accessible portion Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m^2	Yield per length No./km	Yield per length kg/km
Lister and Walker (1966)	Hunts Creek, Qualicum system	-	2.4[8]	1963	6,142	-	-	-	-	2,559	-
				1964	5,488	-	-	-	-	2,287	-
				1965	4,377	-	-	-	-	1,824	-
D.B. Lister (pers. comm.)				1966	5,764	-	-	-	-	2,402	-
				1967	4,988	-	-	-	-	2,078	-
Paine et al. (1975)		-	5.2[8]	1971[9]	3,798	-	-	-	-	730	-
				1972[9]	8,921	-	-	-	-	1,716	-
Sandercock and Minaker (1975)				1973[9]	7,869	7.3	57.4	-	-	1,513	11.0
				1974[9]	6,881[10]	8.1[10]	-	-	-	1,323	-
					6,025	7.7	57.4	-	-	1,826	-
D.B. Lister (pers. comm.)	Capilano River	-	23.3		52,344	-	-	-	-	2,247	-
					60,475	-	-	-	-	2,595	-
					56,410	-	-	-	-	2,421	-
D.B. Lister (pers. comm.)	Cheakamus River	-	15.1	1966	38,667	-	-	-	-	2,561	-
D.B. Lister (pers. comm.)	Cowichan River	-	55.2	1967	152,951	-	-	-	-	2,771	-

8 Lister's estimate of accessible length (2.4 km) excluded high gradient upper reaches and Hunts Creek flood channel. For the period 1971-74 we added our own estimate of the length of the flood channel above the trapping site (2.8 km). R. Harvey (pers. comm.) advised that the flood channel has developed into good rearing habitat.

9 Progeny of both natural and transplanted hatchery fry (probably unfed). Numbers transplanted: 1970 (1969 brood) - 30,833 fry, 1971 - 60,435 fry, 1972 - 130,677 fry.

10 Smolt numbers include 4,095 migrant smolts and 2,786 migrant presmolts. Mean weight (8.1 g) is for smolts only.

Appendix 1 (Cont'd).

Reference	Stream	Accessible portion Area (m^2)	Accessible portion Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m^2	Yield per length No./km	Yield per length kg/km
Agrue et al. (1979)	Rotary Park Ponds[11, 12]	13,561	-	1975	19,121	10.0	191.2	141	1.41	-	-
				1976	10,578	7.9	83.6	78	0.62	-	-
					14,850	9.0	137.4	110	1.01	-	-
	Cowichan Side Channel[12]	2,508	0.82	1975	3,123	6.7	20.9	125	0.83	3,809	25.5
				1976	1,282	7.3	9.4	51	0.37	1,563	11.5
					2,202	7.0	15.1	88	0.60	2,686	18.5
	Pastuch Creek[12]	10,037	3.30	1975	4,118	5.9	24.3	41	0.24	1,248	7.4
				1976	3,520	7.4	26.0	35	0.26	1,067	7.9
					3,819	6.6	25.2	38	0.25	1,157	7.6
	Bible Camp Side Channel[12]	1,832	1.21	1976	2,875	4.9	14.1	157	0.77	2,376	11.7
	Mesachie Creek & Lake[12]	589,975	-	1976	53,309	11.1	591.7	9	0.10	-	-
	Kelvin Creek[13]	56,931	11.42	1976	13,980	10.0	139.8	25	0.25	1,224	12.2

[11] It is our opinion that Rotary Park Ponds are heavily recruited by overwintering juveniles.
[12] Cowichan River tributary.
[13] Koksilah River tributary.

Appendix 1 (Cont'd).

Reference	Stream	Accessible portion Area (m^2)	Accessible portion Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m^2	Yield per length No./km	Yield per length kg/km
Argue and Armstrong (1977)	Meighn Creek[14]	9,809	3.2	1973	8,440	6.4	54.0	86	0.55	2,638	16.9
				1974	5,843	7.5	43.8	60	0.45	1,826	13.7
				1975	2,618	5.6	14.7	27	0.15	818	4.6
					5,634	6.5	37.5	58	0.38	1,761	11.7
	Tenderfoot Creek & Pond[14, 15]	12,380	-	1973	9,239	4.9	45.3	75	0.37	-	-
				1974	4,989	11.5	57.4	40	0.46	-	-
				1975	9,542	6.4	61.1	77	0.49	-	-
					7,923	7.6	54.6	64	0.44	-	-
	Little Stawamus River[16]	12,409	3.7	1974	7,111	6.5	46.2	57	0.37	1,922	12.5
				1975	6,207	5.2	32.3	50	0.26	1,678	8.7
					6,659	5.8	39.2	54	0.32	1,800	10.6
Patterson et al. (1979)	Miller Creek & Pond[17]	17,125	-	1978	5,369	13.5	72.5	31	0.42	-	-
	Bonsall Creek	56,125	11.2	1978	15,820	16.4	259.4	28	0.46	1,413	23.2

14 Squamish River tributary.
15 Tenderfoot Creek dries most summers. Shallow Tenderfoot Pond (Mosley Lake) recedes to half or less of its normal area.
16 Stawamus River tributary.
17 Chemainus River tributary.

Appendix 1 (Cont'd).

Reference	Stream	Accessible portion Area (m^2)	Accessible portion Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m^2	Yield per length No./km	Yield per length kg/km
Hunter (1959)	Hooknose Creek	15,950[18]	2.9[18]	1948	7,959	-	-	50	-	2,744	-
				1949	3,550	-	-	22	-	1,224	-
				1950	2,982	-	-	19	-	1,028	-
				1951	4,389	-	-	28	-	1,513	-
				1952	3,620	-	-	23	-	1,248	-
				1953	4,043	-	-	25	-	1,394	-
				1954	5,987	-	-	38	-	2,064	-
				1955	6,756	-	-	42	-	2,330	-
				1956	4,508	-	-	28	-	1,554	-
				1957	6,074	-	-	38	-	2,094	-
					4,987	-	-	31	-	1,719	-
Narver and Andersen (1974)[19]	Carnation Creek	-	3.47	1971	2,415	-	-	-	-	696	-
				1972	1,879	-	-	-	-	541	-
				1973	1,750	-	-	-	-	504	-
				1974	2,474	-	-	-	-	713	-
					2,130	-	-	-	-	614	-
Clark (MS 1978)[20]	Black Creek	-	30.6[21]	1978	46,514	15.2	707.0	-	-	1,520	23.1
				1979	45,868	-	-	-	-	1,499	
					46,191	-	707.0	-	-	1,510	23.1

[18] Length (2.9 km) given in Hunter (1959), does not include 2.6 km Port John Lake at the headwaters. Area is based on stream width (5.5 m) given in Wickett and Ballantyne (1976).

[19] Additional reference is Andersen and Narver (1975).

[20] Additional reference is LeChasseur (MS 1979).

[21] Length data given in Hamilton (1978).

Appendix 1 (Cont'd).

Reference	Stream	Accessible portion Area (m^2)	Accessible portion Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m^2	Yield per length No./km	Yield per length kg/km
R. Peterson (pers. comm.)	Salmon River (Langley)	60,000[22]	17.4	1979	42,275	10.9	460.8	70	0.77	2,430	26.5
Peterson (MS 1980)	Spring-fed pond # 1	8,498	-	1978	3,613	11.8	42.6	43	0.50	-	-
	Spring-fed pond # 2 Clearwater River, Washington.[23]	12,869	-	1978	1,534	19.3	29.6	12	0.23	-	-
Wickett (1951)	Nile Creek	25,600	5.6	1946	4,078	-	-	16	-	728	-
				1947	3,388	-	-	13	-	605	-
W.P. Wickett (pers. comm.)				1948	5,626	-	-	22	-	1,005	-
				1949	6,227	-	-	24	-	1,112	-
				1950	3,577	-	-	14	-	639	-
				1951	-	-	-	-	-	-	-
				1952	5,949	-	-	23	-	1,062	-
				1953	3,946	-	-	15	-	705	-
				1954	6,995	-	-	27	-	1,249	-
					4,973	-	-	19	-	888	-

22 R. Ptolemy (pers. comm.).

23 Recruitment of juveniles to these ponds occurs mainly during mainstem freshets in fall and winter.

Appendix 1 (Cont'd).

Reference	Stream	Accessible portion Area (m^2)	Accessible portion Length (km)	Smolt year	No. smolts	Mean wt. (g)	Biomass (kg)	Yield per area No./100 m^2	Yield per area kg/100 m^2	Yield per length No./km	Yield per length kg/km
Foerster and Ricker (1953)	Cultus Lake[24]	6,272,850[25]	-	1927	1,577	-	-	0.03	-	-	-
				1929	2,200	-	-	0.04	-	-	-
				1930	182[26]	-	-	0	-	-	-
				1932	1,274	-	-	0.02	-	-	-
				1937	1,868	-	-	0.03	-	-	-
				1938	3,267[27]	-	-	0.05	-	-	-
				1939	649[28]	-	-	0.01	-	-	-
				1940	3,687	-	-	0.06	-	-	-
				1941	3,558	-	-	0.06	-	-	-
				1942	351	-	-	0.01	-	-	-
					1,861	-	-	0.03	-	-	-
W.P. Wickett (pers. comm.)	Chef Creek above fence # 2	-	-	1961	8,841	-	-	-	-	-	-
		12,000	4.02	1962	6,562	-	-	55	-	1,631	-
		15,200	5.06	1963	9,826	9.19	90.3	65	0.59	1,942	17.8
		16,900	5.64	1964	12,220	11.1	135.6	72	0.80	2,167	24.0
	Chef Creek between fences	4,700[29]	0.8	1962	4,955	-	-	105	-	6,194	-
				1963	4,665	8.13	37.9	99	0.81	5,831	47.4
				1964	5,897	10.3	60.7	125	1.29	7,371	75.9
	Chef Creek total system	16,700	4.8	1962	11,517	-	-	69	-	2,399	-
		19,900	5.9	1963	14,491	8.85	128.2	73	0.64	2,456	21.7
		21,600	6.4	1964	18,117	10.8	195.7	84	0.91	2,831	30.6
		19,400	5.7		14,708	9.8	162.0	75	0.78	2,562	26.2

[24] Trapping gear was not operated during the entire smolt migration period. The longest trapping period was in 1940. Counts of two year old smolts were incomplete most years, but were a small proportion of the total.

[25] Surface Area of Cultus Lake from V. Ogilvie (pers. comm.).

[26] Progeny of artificially spawned fish (about 350 females). Planting method and numbers released not known.

[27] Progeny of artificially spawned fish (about 1.1 M eggs). Eyed eggs were planted in creeks above the lake.

[28] Progeny of outlet stream spawners. No natural spawners were allowed to pass into the lake in 1937. Production thought to result from outlet stream presmolts wandering into the lake.

[29] Includes a 2,300 m^2 beaver pond.