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Stream Gradients and Atlantic Salmon Parr Densities

by

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ABSTRACT

Relationships were examined between juvenile densities of Atlantic salmon in six measured stream gradients and eleven measured or estimated physical stream attributes of the Stewiacke River, Nova Scotia. Significant ($p < .005$) second order polynomial regressions of age-1^+ parr densities on area-weighted surface gradient and area-weighted bottom gradient suggest that 1^+ parr densities are a maximum at 'preferred' gradients. The potential for utilizing 5m contour intervals from orthophotographic maps as a basis for habitat pro-rated stream production models is discussed.

RESUME

On a étudié les relations entre les densités de saumons de l'Atlantique juvéniles et six gradients de ruisseau mesurés ainsi que onze attributs physiques mesurés et estimés de la Stewiacke River en Nouvelle-Ecosse. Des regressions polynominals significatives ($P < .005$) de deuxieme ordre sur les densités des parrs 1+ pour des gradients de surface et de fond a surface pondérée indiquent que les densités de parrs 1+ sont maximales pour les gradients preferentiels. On discute par la suite de la possibilité de se servir des cartes orthophotographiques a contour de 5m comme base pour des modèles au prorata de production en cours d'eau.

INTRODUCTION

Current models used to assess the production potential of streams for Atlantic salmon (Salmo salar) utilize production area and rates at which the habitat optimally carries eggs, fry and parr through to smolts. Survival and mortality rates between the various stages have been derived for a few study streams (Elson 1957, Power 1969; Chadwick 1982). Using these rates in assessment models however assumes that estimates of production area for the study and modeled streams were derived in the same manner and that a habitat production rate for a modeled stream will be the same as that of the study stream. Due to the physical, and consequently ecological diversity of most streams these assumptions are frequently invalid. Because of the increasing requirement to assess regional salmon production on the basis of index rivers, this paper provides evidence to support a method of 1) defining criteria for the selection of production areas of a stream and 2) prorating the areas to a functional or weighted production rate.

Depths, bottom composition, surface characteristics etc. are routinely recorded during stream surveys. However, current freshwater assessment techniques do not quantitatively use these data. Reasons range from the absence of clear functional relationships between habitat characteristics and population levels to the lack of such information on a wide enough scale to be employed in a habitat prorated production model.

While it may be physically possible to acquire enough habitat-typing data for a particular stream for a productiom model, it is currently impractical to gather enough field data for all streams requiring assessments. Therefore a habitat accounting parameter which could be derived from readily available remotely captured data sets would be invaluable.

Habitat suitability and preference has been studied for many salmonids with functional relationships having been demonstrated for nose velocity, depth and substrate-size (Shirvell and Dungey 1983; Kennedy and Strange 1982). Studies of habitat suitability for Atlantic salmon indicate that nose velocity and substrate-size are preferentially chosen by juvenile salmon (Rimmer et al. 1984).

Distribution of bottom substrates in streams is a function of water velocity and substrate size. Riffles, defined as shallower sections, tend to have larger substrate sizes than pools (Yang 1971; Dunne and Leopold 1978). Velocity is a function of depth, friction and slope and is described by the Chezy Formula and Manning relation (Dunne and Lepold 1978). These formulae reveal that for streams with rocky and variable reaches, slope and mean depth are the principle components of velocity. Depth is primarily dependent on discharge (for discharges below bank-full width) and may be considered a constant for a given location if measurements are made within a normal range, e.g., summer-low flows. Thus, slope or gradient remains as the key parameter potentially useful in prorating the production potential of rearing area. Additionally, juvenile densities estimated by present techniques (which eliminate high discharges) will be minimally affected by discharge provided that minimum threshold depths are available for juvenile salmon.

While Huet (1959, 1962) and Jones (1975) demonstrated preferences of different species for different gradients, no relationships have yet been demonstrated between juvenile Atlantic salmon densities and gradient (Symons and Heland 1978; Kennedy and Strange 1982).

An opportunity to test the hypothesis that densities of salmon parr are distributed according to gradient was presented in 1983 as an extension to ground truthing the measurement and interpretation of Atlantic salmon habitat from 1:10,000 color aerial photography of the Stewiacke River, Nova Scotia (Fig. 1). In that process mid-stream gradient was determined for several streams. Later, long sections (200-400 m) of the same streams were electrofished to provide mark/recapture estimates of parr densities. The relationship between survey measurements and population densities was then examined. The utility of remotely sensed gradient data in these relationships was also examined.

METHODS AND MATERIALS

Stream surveys were conducted within ecological units termed reaches. Reaches had similar surface, bottom and width characteristics and a maximum length of 30 m. Widths and mid-stream lengths were measured (to 10^{-2} m) at the terminal point of each reach with a fiber measuring tape. Depths (to 10^{-3} m) were measured with a survey rod at one quarter intervals across a transect at the terminal point. The center-depth location was also sighted as the center-line profile using an engineering auto-level and standard levelling techniques. Percentage ledge rock for an entire reach was estimated and then the bottom composition was estimated by partitioning out of 100%, the percentage of boulder, cobble, gravel and sand according to the following size classification: > 30 cm, 10-30 cm, 1-10 cm, < 1 cm, respectively. Water surface condition was classified for an entire reach into the percent smooth, riffle (rolling surface) rough (standing waves > 5 cm) and broken (white water showing).

For stream sections which were later electrofished, the area was calculated as the product of the average width for the beginning and ending points of the reach and the reach length. Percent bottom grade was calculated using change in elevation over the reach length. Percent surface grade was similarly derived with the addition of middle depth measurements. Area-weighted-percent-grade of each section, for which juvenile salmon density was estimated, was calculated using each contributing reach area as the weight for both bottom and surface gradients. Bottom and surface gradients were calculated using the total change in elevation over the total length of a section. Surface slopes < 0.0 were adjusted to 0.0 for area-weighted-percent surface grades.

Stream profile data for the entire Stewiacke River were collected by digital measurement of stream lengths between 5 m contour intervals given on 1:10,000 orthophotographic maps (L.R.I.S, 1978, from 1973 photography)[1]. Stream gradients for each 5 m contour interval and length-weighted-moving-average-percent grade where the sampling frequency was 5 meters over a 15 m rise in elevation were calculated for each stream.

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[1]Land Registration and Information System, Surveys and Mapping Division, Summerside, P.E.I.

Distance of all electrofishing stations above the confluence with the main river was digitally measured by locating the position of the station on the orthophotographic maps. Orthophoto gradient was assigned to each station according to location. Orthophoto weighted-moving-average-percent grade was assigned each station by selecting the interval with the least difference between the section location and the mid-point of the interval.

Adjusted Peterson population estimates (Ricker, 1975) were calculated for juvenile salmon from mark-recapture data collected by electrofishing on various dates from three sites on Newton Brook and two sites on the main Stewiacke River. Population estimates for specific sections within these sites were made possible by differential fin clipping. Depths, widths and lengths were measured after the final sweep. Electrofishing was conducted using a shore-mounted, generator-driven transformer (Coffelt VVP-2C)[2], single anode, lipseine and dip nets operated in a cross-current pattern from bottom to top markers of the site. One to three days generally passed between marking and sampling runs. All fish were measured to a 0.5 cm total length interval permitting population estimates by age-class.

Pearson correlation coefficients between age-class densities and all physical variables were calculated.

The accuracy and thus the representativeness of orthophotographic measured gradient data was checked by sampling elevations from field data where a sum length coincided within $\pm$ 10 m of a contour interval crossing the stream. Percent-gradient tables for each data set were then constructed and after conversion to $\sin^{-1} \sqrt{p}$ compared by a two-way analysis of variance.

RESULTS

Stream surveys and elevations were completed for 5.6 km of Newton Brook and 6.4 km of the upper portion of the main Stewiacke River. Detailed descriptions (Table 1) of the electrofished sections of these streams indicate the range of gradients for the bottom (-0.97 to 5.77%) and surface (-0.11 to 6.61%). Section areas ranged from 303 to 2870 m^2 sections contained up to 11 reaches with areas ranging from 23 to 314 m^2. Densities of age-1^+ parr ranged from 0.8 to 52.5 $\cdot\ m^{-2} \times 10^2$ and were generally unbiased (Ricker 1975, p. 79). However, the estimates for the upper main Stewiacke section 1, where only three parr were captured, were not possible by mark/recapture. Therefore, first catch efficiency (P=.45), suggested by data for other sites, was applied to the initial catch to estimate the population. Since the density estimate of age-1^+ parr for this population were $< 1.0\ \cdot\ M^2 \times 10^2$, a value of 1.1 $\cdot\ m^2 \times 10^2$ was used in later analysis.

Stream gradients gathered from orthophotographic maps for the main Stewiacke River and Newton Brook covered 88.0 and 7.9 km, respectively (Tables 2 and 3). Gradients ranged from 0.03 to 2.35% and 0.64 to 4.52%, whereas length-weighted- moving-average gradients ranged from 0.03 to 1.81% and 0.91 to 2.46% for the main Stewiacke and Newton Brook.

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[2]Coffelt Electronics, 2019 West Union Ave. Englewood, Colorado, 80110.

Percent grades (Table 4) for six gradient variables were calculated from the recorded physical surveys in order to test the hypothesis. An additional 11 variables measuring or estimating different physical attributes of the sections were calculated, and the relationship between the estimated densities and these variables were examined (Table 5).

Regressions of age-1+ and age-2+ juvenile salmon densities on physical data (Table 5) revealed seven significant correlation coefficients for 1+ parr (2 at $p < 0.01$ and 5 at $p < 0.05$) and one significant correlation coefficient for 2+ parr.

Age-1+ parr densities were significantly correlated (1 at $p < 0.01$ and 3 at $p < 0.05$) with four of the six gradient-related variables; length-weighted-moving-average gradient from the ortho data ($r=0.733$; $p < 0.01$); bottom gradient ($r=0.658$; $p < 0.05$); area-weighted bottom gradient ($r=0.671$; $p < 0.05$) and area-weighted surface gradient ($r=0.646$; $p < 0.05$).

Densities of 1^+ parr were significantly ($p < 0.01$ and $p < 0.05$) negatively correlated with area-weighted percent sand ($r=-0.893$) and area-weighted percent smooth ($r=-0.713$). These subjectively estimated variables were themselves significantly correlated ($r=0.740$; $p < 0.05$). While neither variable was significantly ($p=0.05$) correlated to the ortho-gradient variables, area-weighted percent sand was significantly negatively correlated ($p=0.05$) for all field measured gradient data ($r=-0.703$, -0.681, -0.684, -0.667 for overall bottom and surface gradient and area-weighted bottom and surface gradient, respectively).

Age-2^+ parr densities were significantly ($p < 0.01$) positively correlated to area-weighted percent boulder ($r=0.880$; $p < .01$). Area-weighted percent boulder was not significantly ($p=0.05$) correlated to any gradient variable. Densities of age-2^+ parr were positively correlated ($p < 0.01$) with area-weighted percent boulder but were not significantly correlated with any gradient variable.

In order to test the postulate that age-1+ parr density has a maximum density associated with a preferred gradient, second order polynomial regressions were calculated for age-1+ parr densities on all gradient-related variables transformed by $\sin^{-1} \sqrt{p}$ to normalize the distributions. Significant regressions include age 1+ parr density on area-weighted surface gradient ($p < 0.005$); area-weighted bottom gradient ($p < 0.005$); bottom gradient ($p < 0.05$) and length-weighted moving-average ortho gradient ($p < 0.05$)(Table 6). Plots with fitted curves of age-1+ parr density on area-weighted surface gradient, (e.g., in No. 6) and length-weighted-moving-average ortho gradient (e.g., in No. 2) are presented in Figures 2 and 3, respectively. Age-1+ parr had a calculated maxima at an area-weighted surface gradient of 1.33 percent.

DISCUSSION

Evidence presented suggests that all salmon habitat types, for which gradient is a quantitative indicator, do not support the same level of age-1^+ parr densities. These data provide for the first time, a link between a quantitative variable and the habitat parameter.

Reasons why Symons and Heland (1978), Kennedy and Strange (1982), and Gordon and MacCrimmon (1982) failed to demonstrate significant parr density and gradient relationships may include the use of smaller sample areas and less discrete collection and treatment of the data.

Although the data presented are not distributed over the total range of possible gradient values, results suggest that age-1^+ parr are distributed in a stream according to gradient. Interestingly this density-gradient distribution is similar to the probability-of-use curves for rainbow trout (Salmo gairdneri) and velocity (Bovee 1978) and brown trout (Salmo trutta) and velocity (Shirvell and Dungey 1983) and Atlantic salmon and velocity (Rimmer et al., 1984).

Since densities of age-2^+ fish were significantly ($p < 0.01$) positively correlated with area-weighted percent boulder but were not significantly correlated with any gradient variable suggest other criteria besides gradient are being used to select habitat and that subjective estimation of percent boulder in some way accounts for this distribution. The lack of correlation between boulder and gradient is inconsistent with the substrate distribution theory offered by Yang (1971) and Dunne and Leopold (1978). It is evident then that other factors such as geomorphology and hydrology also function in the distribution of larger substrates and because of their mass, clumping or under distribution likely occurs.

The significant ($p < .05$) relation between distance of the sites from mouth of the river and area-weighted percent boulder may provide valuable input to a distribution model for age-2^+ parr particularly if data could be treated within stream orders or at least within tributaries. Further evidence for suggesting increasing density of age-2^+ - parr with increasing distance to mouth is the significant ($p < .05$) negative correlation ($r=0.604$) for age-1^+ parr density and distance to mouth.

The relatively low densities of age-2^+ parr estimated for the Stewiacke River and Newton Brook ($\bar{X}=6.3 \pm 3.63$ (95% CL) and the mixture of stream orders possibly masks any underlying relationship to gradient, distance to mouth or depth. Indeed the manner of sampling depths (at the end of reaches) would not be expected to representatively sample overall reach depth and therefore show previously documented significant correlations (Kennedy and Strange, 1982; Egglishaw and Shackley, 1982).

Significant (p.0.05) correlations between densities of age-1^+ and age-2^+ parr for some of the subjectively estimated variables suggest that criteria quantifying habitat represented quantitative variables.

Variation in juvenile stock abundance due to recruitment and/or survival to age-1+ parr and older may be accounted for by calibrating a density-gradient curve for a particular stream or river on a yearly basis. This is possible since the preferential selection of habitat demonstrated for velocity, substrate and depth for Atlantic salmon likely functions independently of density. Thus, calibrating the curve for a particular stock level is consistent with that hypothesis. Maximum fish densities for the Stewiacke are among the highest values reported in the literature and these may approximate densities at carrying capacity. Application of the curve presented to gradient prorated production estimates would then be appropriate for estimating maximum production of similar geographic streams.

Absence of a relationship between parr densities and ortho-measured gradients and the significant fit of parr densities and length-weighted moving-average ortho gradient is perplexing since they both measure gradient. The possibility that ortho-measured gradients were inaccurate was examined by sampling elevations, from orthophotographic and field-measured gradient data, for Newton Brook. High correlation ($r=0.997$) between elevations at sample locations and the lack of a significant difference ($F=.65$, $p \ll 0.01$) between their paired gradients ($\sin^{-1} \sqrt{p/100}$) suggest this was not the case.

Ranges in orthophoto collected gradient variables (Table 2) provides an indication of why a better correlation for the length-weighted variable occurred. Briefly, within a site consisting of two to four sections, the moving-average gradient values changed at least once per site whereas the straight ortho gradient was homegenous within a site. This finding is the result of the proximity of the site and the mid-point of more than one moving-average interval whereas all sites occurred within one continuous ortho gradient interval. The effect is to allow values in the proximity of the sampling location to affect the assigned gradient value which in this case improved the regression.

Lack of significance for the X^2 (second order) term in the regression of age-1^+ parr on length-weighted-moving-average percent gradient indicated that the appropriate model was linear ($r=0.66$; $p=0.01$)(Fig. 3). This is not surprising since the smoothing effect of moving-average places all observations below the maxima gradients observed for area-weighted percent surface gradient. In order to define the curve past the range of data presented, sampling would have to occur at higher gradient intervals.

Applying ortho-collected gradient data to a production model will not be straightforward since only length-weighted-moving-average ortho gradient was shown to have a significant relation. Since moving-average intervals will require further treatment to input to such a model, alternative treatment of the data may provide similar results. One such alternative may be to investigate the relationship between pool:riffle ratios and pool lengths for various gradient segments so that the production rate of pools can be treated separately.

The data and analysis presented indicate that before prorated habitat models for salmon streams can be developed, more intensive sampling of parr densities over the complete range of gradients, distance to mouth, and over the total length of ortho-gradient intervals is required.

The preliminary results reported here would suggest that ortho map gradient data coupled with aerial photographic survey techniques and electrofishing data gathered specifically to define the density-gradient curves for rivers would provide improved models for required egg deposition, potential smolt production and assessment of the abundance of juvenile salmon.

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Table 1. Summaries of reach lengths and widths contributing to area-weighted-bottom and surface grades and electrofishing parameters and population estimates of juvenile salmon for the Stewiacke River, 1983.

Station Site No. Section	Reach parameters: Length m	Avg. width m	Area m^2	% Btm grade	% Sur grade	% bedrock	Electrofishing parameter: Area m^2	Dates	Population parameters: Parr age	$\frac{M+1 \quad C+1}{R+1}$	$= P^a$	Density/ 100 m^2
Newton Bk.	30.0	8.3	249	.33	.13		1,163	July 18&19	1+	$\frac{142 \bullet 136}{68}$	= 284	24.4
#1	15.5	6.1	95	-.97	.45							
1+2	10.9	5.8	63	2.94	1.19							
	10.6	8.1	85	1.23	1.42				2+	$\frac{16 \bullet 19}{11}$	= 28	2.4
	18.2	9.7	177	-.11	.33							
	17.8	7.2	128	.11	.45							
	15.0	7.2	107	2.73	1.73							
	27.2	7.4	201	-.15	.15							
	18.6	4.7	87	.05	.54							
	20.1	4.1	81	.95	.85							
	14.5	5.8	84	2.55	1.93							
	30.0	6.5	195	-.07	-.07		1,100	July 18&19				
	30.0	4.8	144	1.00	1.17				1+	$\frac{95 \bullet 87}{31}$	= 267	24.2
3+4	30.0	5.3	159	.83	.77							
	30.0	9.1	272	1.57	1.03							
	30.0	10.5	314	-.10	.20				2+	$\frac{14 \bullet 15}{7}$	= 30	2.7
	30.0	8.1	243	0.00	.33							
5	15.3	9.6	147	.13	.07		1,540	July 27&29				
	20.9	8.2	170	.17	.50							
	30.0	6.9	206	.65	.82				1+	$\frac{242 \bullet 207}{83}$	= 604	39.2
	30.0	7.4	222	1.80	1.67							
	30.0	8.4	252	-.03	.07							
	15.8	8.3	130	.73	.09				2+	$\frac{41 \bullet 24}{13}$	= 76	4.9
	18.6	8.9	165	1.05	1.53							
	27.1	9.3	252	.22	.15							
6	30.0	7.4	222	.65	.72		873	July 27&29				
	22.5	7.4	167	.53	.89				1+	$\frac{98 \bullet 89}{36}$	= 242	27.7
	19.8	8.6	170	1.04	.83							
	19.2	9.2	177	.21	.05				2+	$\frac{12 \bullet 9}{6}$	= 18	2.1

Table 1. Cont'd

Station Site No. Section	Reach parameters: Length m	Avg. width m	Area m^2	% Btm grade	% Sur grade	% bedrock	Electrofishing parameter: Area m^2	Dates	Population parameters: Parr age	$\frac{M+1 \quad C+1}{R+1} = P^a$	Density/ 100 m^2
Newton Bk.											
#2	8.8	5.1	45	.57	-.11		1,060	July 20&21			
1	11.7	6.7	78	2.65	1.88						
	30.0	7.0	210	.30	-.03	70			1+	$\frac{217 \bullet 182}{71}$ = 556	52.5
	7.6	5.7	43	3.29	4.08	90					
	25.7	5.9	150	.43	.39	90			2+	$\frac{27 \bullet 27}{10}$ = 73	6.9
	18.1	6.0	108	4.34	4.28	100					
	18.6	6.0	111	-.30	.19	90					
	19.0	7.8	148	2.53	1.95	80					
	5.9	10.2	60	5.42	6.61	90					
	30.0	8.9	266	.30	.43	50					
	27.8	5.9	164	.32	.07	30					
	23.2	5.4	124	1.29	.73	30	1,080	July 20&21			
2	30.0	7.7	230	2.37	2.53	40					
	13.5	7.9	107	2.56	3.89	100			1+	$\frac{154 \bullet 153}{58}$ = 406	37.6
	21.7	5.4	117	-.99	.02	40					
	11.7	4.8	56	4.40	3.38	100					
	20.8	4.7	97	1.30	.10	80			2+	$\frac{17 \bullet 20}{8}$ = 42	3.9
	27.6	4.9	134	2.36	2.57	90					
	22.9	5.3	121	2.82	2.99	80					
	19.0	10.2	194	2.21	1.68	90					
#3	30.0	4.0	119	1.10	1.43		1,100	July 25&26	1+	$\frac{234 \bullet 203}{121}$ = 393	35.7
1	30.0	3.8	113	1.06	1.02						
	30.0	4.3	128	1.60	1.67						
	30.0	5.7	170	2.57	2.07				2+	$\frac{53 \bullet 45}{29}$ = 82	7.5
	30.0	6.7	200	.87	1.10						
	30.0	5.9	177	1.23	1.37						
	30.0	4.7	140	.70	.67						

Table 1. Cont'd

Station Site No. Section	Reach parameters: Length m	Avg. width m	Area m^2	% Btm grade	% Sur grade	% bedrock	Electrofishing parameter: Area m^2	Dates	Population parameters: Parr age	$\frac{M+1 \quad C+1}{R+1}$	$= P^a$	Density/ 100 m^2
	30.0	4.4	132	1.67	1.60	0	591	July 25&26				
2	21.8	4.3	93	1.47	1.42	0						
	21.6	3.7	80	.07	.35	0				$\frac{130 \bullet 100}{59}$	= 220	37.3
	15.6	3.7	58	2.05	2.56	70						
	16.5	4.0	66	1.48	.94	0			1+			
	7.1	4.3	30	5.77	5.07	100				$\frac{21 \bullet 21}{5}$	= 8	1.4
	15.3	4.2	64	-.36	.16	40			2+			
Upper Main Stewiacke												
	19.5	5.8	113	2.15	1.38		567	July 28&Aug 2				
1	30.0	7.2	215	-.97	0.0				1+	2 @ p = .45	4.4	.8 (1.1)
	29.3	6.6	193	.51	0.0							
									2+	1 @ p = .45	2.2	.4 (1.1)
	4.0	5.7	23	2.50	3.00		458					
2	19.3	3.1	60	.36	-.05							
	25.2	2.3	58	1.29	1.41				1+	$\frac{62 \bullet 71}{30}$	= 147	32.1
	24.5	3.0	72	.12	.20							
	18.5	3.8	69	.27	.32				2+	$\frac{30 \bullet 28}{7}$	= 120	26.2
	21.3	2.8	59	2.54	2.35							
3		Not available					409	July 28&Aug 2	1+	$\frac{21 \bullet 38}{8}$	= 100	24.4
									2+	$\frac{12 \bullet 14}{6}$	= 28	6.8
									3+	1 @ p = .45	= 2	.5

Table 1. Cont'd

Station Site No. Section	Reach parameters						Electrofishing parameter		Population parameters			
	Length m	Avg. width m	Area m^2	% Btm grade	% Sur grade	% bedrock	Area m^2	Dates	Parr age	$\frac{M+1 \quad C+1}{R+1}$	$= P^a$	Density/ 100 m^2
4	Not available						303	July 28&Aug 2	1+	$\frac{21 \bullet 31}{9}$	= 72	23.9
									2+	$\frac{13 \bullet 18}{8}$	= 29	9.7
									3+	$\frac{5 \bullet 7}{5}$	= 7	2.3
Main Stewiacke												
1	Not available						2,870	Aug 16&29	1+	$\frac{134 \bullet 92}{26}$	= 474	16.5
									2+	$\frac{29 \bullet 22}{7}$	= 91	3.2
2	Not available						2,590		1+	$\frac{96 \bullet 123}{19}$	= 621	24.0
									2+	$\underline{21 \bullet 22}$	= 154	5.9

[a]M = no. marked.
C = no. captured.
R = no. recapture.
P = pop'n estimate

Table 2. Percent-grades and length-weighted-moving-average-percent grades for sections of the main Stewiacke River as determined by digital measurements of orthophotographic maps with 5 m contour intervals.

Contour interval	Distance (km) Start	End	% Grade	Distance (km) Start	End	Len-wt'd moving avg % Grade
1	0.000	13.207	0.03			
2	13.207	37.710	0.02			
3	37.710	56.660	0.03	0.000	56.660	0.03
4	56.660	60.811	0.12	13.207	60.811	0.03
5	60.811	63.965	0.16	37.710	63.965	0.06
6	63.965	66.463	0.20	56.660	66.463	0.15
7	66.463	68.678	0.23	60.811	68.678	0.19
8	68.678	69.696	0.49	63.965	69.696	0.26
9	69.696	71.378	0.30	66.463	71.378	0.31
10	71.378	72.667	0.39	68.678	72.667	0.38
11	72.667	73.567	0.56	69.696	73.567	0.39
12	73.567	74.629	0.47	71.378	74.629	0.46
13	74.629	75.049	1.19	72.667	75.049	0.63
14	75.049	76.278	0.41	73.567	76.278	0.55
15	76.278	77.261	0.51	74.629	77.261	0.57
16	77.261	78.887	0.31	75.049	78.887	0.39
17	78.887	79.525	0.78	76.278	79.525	0.46
18	79.525	80.520	0.50	77.261	80.520	0.46
19	80.520	81.795	0.39	78.887	81.795	0.52
20	81.795	82.402	0.82	79.525	82.402	0.52
21	82.402	83.513	0.45	80.520	83.513	0.50
22	83.513	84.418	0.55	81.795	84.418	0.57
23	84.418	85.425	0.50	82.402	85.425	0.50
24	85.425	85.937	0.98	83.513	85.937	0.62
25	85.937	86.731	0.63	84.418	86.731	0.65
26	86.731	87.171	1.14	85.425	87.171	0.86
27	87.171	87.500	1.52	85.937	87.500	0.96
28	87.500	87.713	2.35	86.731	87.713	1.53
29	87.713	88.000	1.74	87.171	88.000	1.81

Total length = 87.9997 kilometers.
Elevation rises from 5.5 meters to 150 meters.
Length weighted average % grade = 0.16.

Table 3. Percent-grades and length-weighted-moving-average-percent-grades for sections of Newton Brook as determined by digital measurements of orthophotographic maps with 5 m contour intervals.

Contour interval	Distance (km) Start	Distance (km) End	% Grade	Distance (km) Start	Distance (km) End	Len-wt'd moving-avg % Grade
1	0.000	.203	1.48			
2	.203	.990	0.64			
3	.990	1.426	1.15	0.000	1.426	0.91
4	1.426	1.718	1.71	.203	1.718	0.99
5	1.718	2.395	0.74	.990	2.395	1.07
6	2.395	2.506	4.52	1.426	2.506	1.39
7	2.506	3.023	0.97	1.718	3.023	1.15
8	3.023	3.582	0.90	2.395	3.582	1.26
9	3.582	4.059	1.05	2.506	4.059	0.97
10	4.059	4.498	1.14	3.023	4.498	1.02
11	4.498	4.844	1.44	3.582	4.844	1.19
12	4.844	5.224	1.32	4.059	5.224	1.29
13	5.224	5.579	1.41	4.498	5.579	1.39
14	5.579	5.734	3.22	4.844	5.734	1.69
15	5.734	5.906	2.90	5.224	5.906	2.20
16	5.906	6.189	1.77	5.579	6.189	2.46
17	6.189	6.424	2.13	5.734	6.424	2.17
18	6.424	6.678	1.97	5.906	6.678	1.95
19	6.678	6.992	1.59	6.189	6.992	1.87
20	6.992	7.344	1.42	6.424	7.344	1.63
21	7.344	7.559	2.32	6.678	7.559	1.70
22	7.559	7.917	1.40	6.992	7.917	1.62

Total length = 7.9172 kilometers.
Elevation rises from 27 meters to 135 meters.
Length weighted average % grade = 1.36.

Table 4. Physical characteristics, orthophoto gradients and locations of sections of the Stewiacke River electrofished in 1983.

				Percent grade															
			Length to mouth	Ortho		Overall		Area wt'd		Area wt'd %	Area wt'd % Bottom Comp.				Area wt'd avg dep	Area wt'd % Surface			
Stream	Location	St'n	(km)	Raw	Moving	Btm	Surf.	Btm	Surf.	bedrock	B	C	G	S	(cm)	S	Riff.	Rough	Bk.
Newton Bk.	@ Hwy	1+2	.257	.64	.91	.68	.70	.62	.65	0	9	38	42	11	22.8	31	42	23	4
	"	3+4	.457	.64	.91	.54	.57	.50	.54	0	4	33	55	8	23.5	31	55	12	2
	"	5	.657	.64	.91	.29	.31	.63	.66	0	6	44	44	6	15.7	11	85	4	0
	"	6	.857	.64	.99	.61	.64	.61	.62	0	5	38	47	10	14.8	5	70	25	0
Newton Bk.	Bl. old	1	2.000	.74	1.39	1.24	1.15	1.28	1.21	64	2	13	18	3	16.5	26	46	14	13
	dam site	2	2.200	.74	1.26	1.90	1.88	1.97	1.97	69	2	7	20	2	19.9	20	20	18	42
Newton Bk.	Gammels	1	4.756	1.32	1.29	1.30	1.33	1.32	1.34	0	25	44	26	5	21.3	24	62	15	0
	property	2	4.956	1.32	1.39	1.37	1.41	1.39	1.42	18	17	33	22	10	17.6	26	41	29	4
Upper Main	@ Lorne	1	85.68	.98	.65	.00	.04	.26	.30	0	8	36	32	24	20.9	89	11	0	0
	Rd.	2	85.78	.98	.65	.99	.95	.97	.95	0	54	27	13	6	14.9	50	42	8	0
		3	85.90	.62	.65	-	-	-	-	0									
		4	86.00	.62	.86	-	-	-	-	0									
Main River	Above Spring Side	1	75.00	.41	.55	-	-	-	-	0									
		2	75.00	.41	.55	-	-	-	-	0									

Table 5. Correlation coefficients (r) for 1+ and 2+ parr densities ($m^{-2} \times 10^2$) and physical variables. Significance levels of $p = 0.05$ and $p = 0.01$ are indicated by single and double underlines respectively (n for each variable is indicated below name).

Physical variable	1+ Parr (14)	2+ Parr (14)	Physical variable	1+ Parr (14)	2+ Parr (14)
Dist./length to mouth (14)	$\underline{-.604}$	.418	Area wt'd % boulder (10)	.012	$\underline{.880}$
% Gr. orth. (14)	.218	.146	Area wt'd % cobble (10)	-.401	-.161
Len-wt'd % gr orth mov avg (14)	$\underline{\underline{.733}}$	.222	% gravel area wt'd (10)	-.384	-.540
% Gr btm el sect[a] (10)	$\underline{.658}$	.175	Area wt'd % sand (10)	$\underline{\underline{-.893}}$	-.339
% Gr surf el sect (10)	.630	.140	Area wt'd avg depth (10)	-.509	-.392
Area wt'd % gr btm el sect (10)	$\underline{.671}$	.139	Area wt'd % smooth (10)	$\underline{-.713}$	.157
Area wt'd % gr surf el sect. (10)	$\underline{.646}$	.111	Area wt'd % riffle (10)	.419	.030
			Area wt'd % rough	.332	-.295
Area wt'd % bedrock (14)	.609	-.090	Area wt'd % broken	.334	-.124

[a]Electrofishing section.

Table 6. Coefficients of determination (R^2) for second order polynominal regressions with F values and degrees of freedom (df) for regression and two X terms where the dependent 1+ parr ($m^{-2} \times 10^2$) is regressed on all gradient-related variables transformed by arc sine p. Equations for significant regressions $p \leq \underline{0.05}$; $p \leq \underline{0.01}$) shown below.

No.	Independent variable (X)	R^2	F-values Rgn'	F-values X1	F-values X2	df Rgn'	df X1	df X2
1	% gr. ortho.	.050	.29	.18	.40	2, 11	1, 11	1, 11
2	Len-wt'd-mov avg % gr	.546	6.60	12.75	.45	2, 11	1, 11	1, 11
3	% gr bottom el sect[a]	.647	6.43	11.79	1.06	2, 7	1, 7	1, 7
4	% gr surface el sect	.606	5.37	9.21	1.53	2, 7	1, 7	1, 7
5	Area wt'd % gr bottom el sect	.790	13.13	18.40	7.86	2, 7	1, 7	1, 7
6	Area wt'd % gr surface el sect	.790	13.16	17.22	9.10	2, 7	1, 7	1, 7

No.	Equation
2	$Y = 50.89 - 18.22 \sin^{-1} \sqrt{X/100} + 2.2 \sin^{-1} \sqrt{X^2/100}$
3	$Y = 2.99 + 8.73 \sin^{-1} \sqrt{X/100} - .52 \sin^{-1} \sqrt{X^2/100}$
4	$Y = -9.50 + 13.21 \sin^{-1} \sqrt{X/100} - .91 \sin^{-1} \sqrt{X^2/100}$
5	$Y = 80.83 + 36.70 \sin^{-1} \sqrt{X/100} - 2.75 \sin^{-1} \sqrt{X^2/100}$
6	$Y = 99.03 + 42.54 \sin^{-1} \sqrt{X/100} - 3.21 \sin^{-1} \sqrt{X^2/100}$

[a]Electrofishing section.

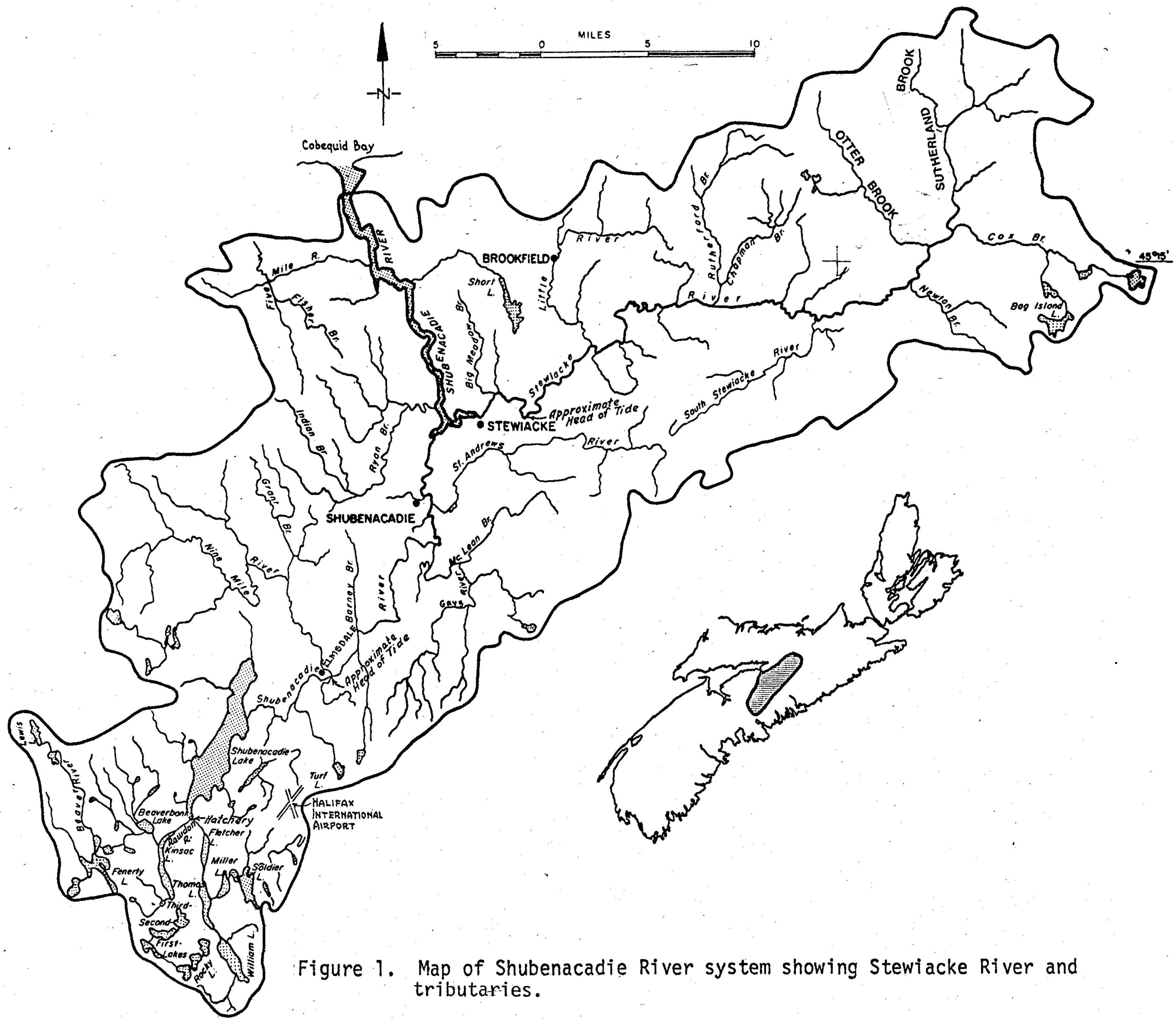

Figure 1. Map of Shubenacadie River system showing Stewiacke River and tributaries.

$$Y = 99.03 + 42.54\ \text{sine}^{-1}\sqrt{X/100} - 3.21\ \text{sine}^{-1}\sqrt{X^2/100}$$

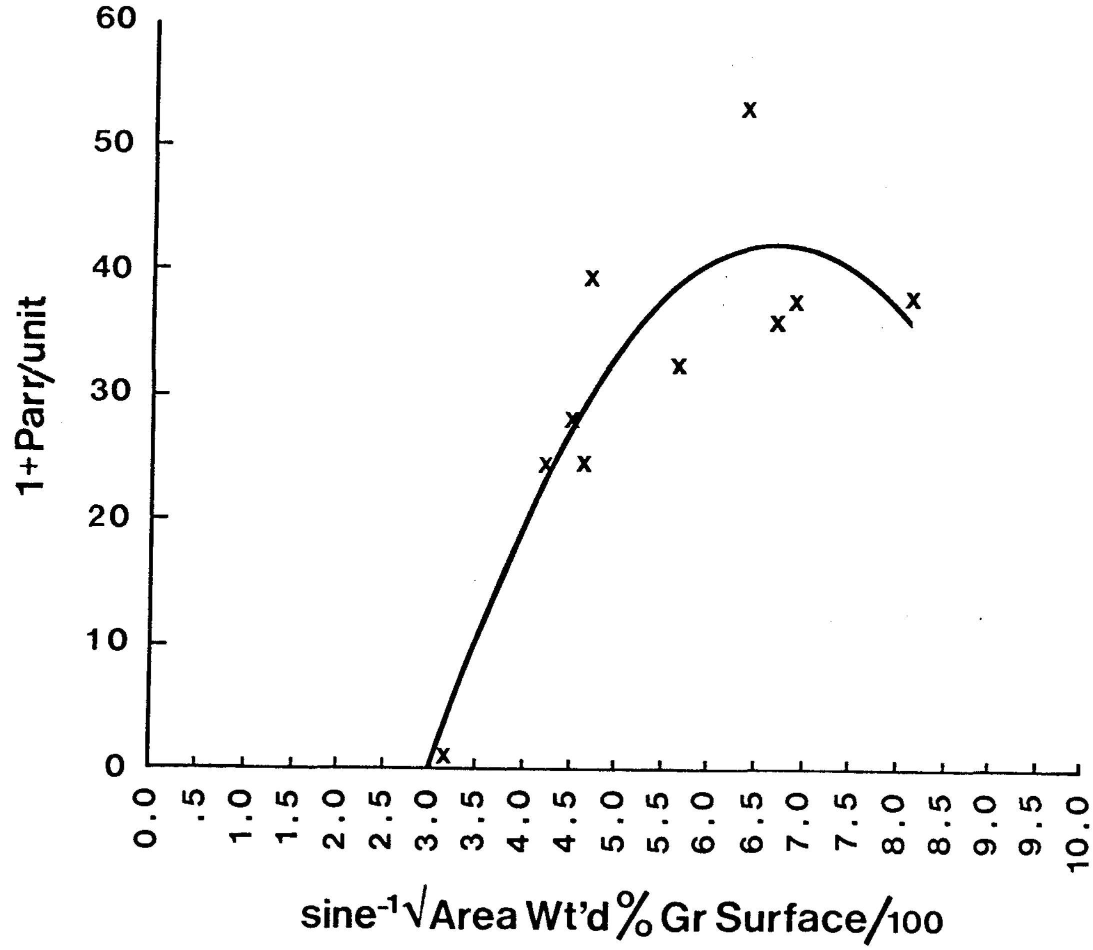

Fig. 2. Relationship between area-weighted percent-grade and 1+ parr/100 m^2 unit with fitted quadratic equation for sites electrofished in the Stewiacke River and tributaries in 1983.

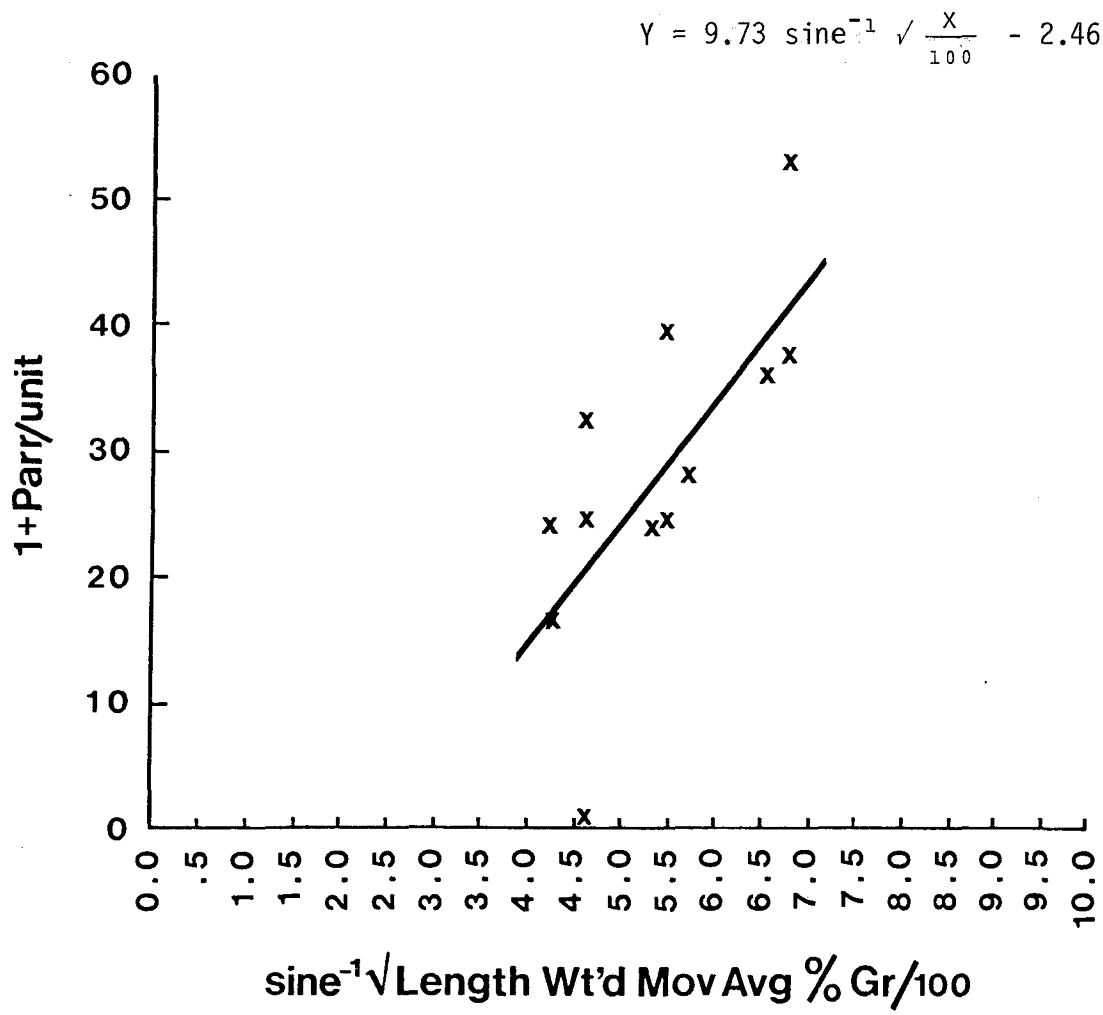

Fig. 3. Relationship between length-weighted moving-average percent-grade and 1+ parr/100 m^2 with fitted equation for sites electrofished in the Stewiacke River and tributaries in 1983.