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BROOK TROUT *Salvelinus fontinalis* (Mitchill), POPULATION DYNAMICS AND RECREATIONAL FISHERY IN INDIAN BAY BROOK, NEWFOUNDLAND (1995-1998)

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ABSTRACT

In response to anglers allegations of declining fishery, a monitoring and research program was initiated in Indian Bay Brook watershed. The program was designed to collect life history information and fisheries information on brook trout. The results presented describe the life history and recreational fishery and provide initial input parameters needed to develop a brook trout exploitation model. The brook trout exploitation model is described in a companion paper (Lester, Korver, van Zyll de Jong, Norris and Wicks 1999). It is anticipated that the data presented and the model describing brook trout exploitation will provide a scientific basis from which management guidelines and further data requirements can be developed.

RÉSUMÉ

En réponse aux allégations de pêcheurs à la ligne que la pêche fléchissait, un programme de contrôle et de recherche a été lancé dans le bassin hydrographique de Indian Bay Brook. Le programme visait à rassembler des données sur le cycle de vie et les pêches de l'omble de fontaine. Les résultats présentés décrivent le cycle de vie et la pêche récréative tout en fournissant les paramètres d'entrée initiaux requis pour préparer un modèle d'exploitation de l'omble de fontaine. Ce modèle d'exploitation est décrit dans un document connexe (Lester, Korver, van Zyll de Jong, Norris et Wicks 1999). On prévoit que les données présentées, ainsi que le modèle décrivant l'exploitation de l'omble de fontaine, établiront une base scientifique qui servira à la préparation de lignes directrices de gestion et à la collecte de données additionnelles.

INTRODUCTION

The brook trout, Salvelinus fontinalis (Mitchill), is the most common freshwater sport fish in Newfoundland with respect to both its distribution (Scott and Crossman 1973) and it's importance with anglers (DFO 1995). Despite this, current management regulations are determined in the absence of data. The absence of data driven management coupled with historically high participation rates (DFO 1995) has resulted in the commonly held view by anglers that brook trout are declining in individual size and stock abundance. Despite anglers allegations of a declining fishery, few studies have been conducted on brook trout population dynamics (e.g., Knoechel and Ryan 1994; Ryan and Knoechel 1994; de Graff 1983; Ryan 1984) or the fisheries exploiting them in Newfoundland lakes (e.g., Wiseman 1969; Fowlow, Hoenig and van Zyll de Jong and 1997). In addition comparative studies and simulation studies on the effects of management strategies on Newfoundland brook trout are absent in the literature. This paucity of fundamental data limits our ability to provide scientifically defensible management actions or plans.

In an effort to remedy this information gap, a multi-year research project in Indian Bay Brook, Newfoundland was initiated in 1995. The results presented summarize and describe the population dynamics and fishery of Indian Bay brook trout and provide initial input parameters needed to develop a brook trout exploitation model. The brook trout exploitation model is described in a companion paper (Lester, Korver, van Zyll de Jong, Norris and Wicks 1999). It is anticipated that the data presented and the model describing brook trout exploitation will provide a scientific basis from which management guidelines and further data requirements can be developed.

STUDY AREA

Indian Bay Brook (Fig. 1) flows northeast from the upper section of the Bonavista Peninsula into Bonavista Bay (51° 10' 10" N ; 56° 01' 25" W). From 1995 to 1998, 15 lakes were sampled using a standard stock assessment program (van Zyll de Jong , in preparation). Many of these lakes were sampled in multiple years yielding a total of 40 lake projects. Lake name, location and physical and chemical characteristics are listed in Table 1. The watershed lies in the central Newfoundland ecoregion (Damman 1980). Pure black spruce forests and Aspen stands dominate the area due to the prevalence of fire in the natural history of the region. The topography is rolling to undulating and is characterized by sandy loam soils. All ponds sampled supports populations of brook trout, Salvelinus fontinalis (Mitchill), Atlantic salmon, Salmo salar (L), ouananiche , Salmo salar ouananiche (McCarthy), Rainbow smelt, Omerus mordax (Mitchill), American eel, Anguilla rostrata (Lesueur), and three-spined stickleback, Gasterosteus aculeatus (L). In addition Big Wings Pond supports a population of Arctic charr, Salvelinus alpinus (L), and in Third Pond, Backup Pond and Second Pond banded killifish, Fundulus diaphanus (Lesueur), have been observed in net catches.

METHODS

Lake bathymetric and habitat maps were completed for all lakes surveyed using standardized methods (OMNR 1983). For these maps the following lake attributes were calculated; surface area, lake perimeter, shoreline development and mean lake depth. Habitat information collected included bottom substrate, extent of aquatic vegetation, the extent of exposed shoreline and human developments. Water quality parameters measured included dissolved oxygen (DO), standard pH, temperature, specific conductance and total dissolved solids.

Standardized index netting surveys were conducted during the summers of 1995-1998. Lake sampled, year and number of sets are indicated in Table 4. Standardized fyke nets were set with a *30m* lead extending perpendicular to the shore. The hoop opening was standardized at *2.25* m^2, with a series of *5* smaller hoops at *1.0* m^2 extending back from the first hoop forming a funnel. Mesh size was uniform at 10 mm in width. Material used was black knotless mulitfilament polyester. Effort duration (24 hr sets) and net orientation (perpendicular to the shore) were fixed during the surveys. Capture methodology standards and guidelines are indicated in Table 2. All sites were chosen independently of the samplers knowledge of "good sites". Sites were attributed a site code, and a random number table was used to select sampling units for the survey period. To assess year-to-year changes in abundance effectively, sampling was allocated to one season, the spring. The spring littoral zone was chosen as a representative habitat that would accurately characterize the population. In the spring many species that inhabitat deeper colder water during the thermal stratification period are dispersed throughout the water column, and it is easier to obtain a good cross-section of the fish population (Lester 1991). The survey incorporated a physical space (i.e., littoral zone), time (i.e. spring), temperature window (e.g., start survey when surface temperatures reach 9 °C and ending when surface temperatures exceed 19 °C) and any number of other factors coincidental in the sampling design. In addition to standard spring netting, each year reproductive surveys were carried in the fall. Reproductive surveys followed the same methodological standards and guidelines as the spring surveys, except temperature ranges did not apply.

Fish species captured were collected, identified, enumerated and measured for fork length (to the nearest mm) and weight (0.1 gram). Brook trout were tagged with lake specific colour and individually numbered fingerling floy tags and released for mark-recapture studies. An otolith and scales were collected for age interpretation from a sub-sample of the catch. Calcified structures were prepared for age interpretation according to methods outlined by Casselman (unpublished). All calcified structures were interpreted for age and growth using the program CSAGES (Calcified Structure Age and Growth Extraction Software) (Casselman, Barnes and Brown 1994, under development). At each netting site general weather conditions (i.e, precipitation, cloud cover, wind direction and speed) and site specific habitat attributes (i.e., substrate, macrophyte cover, depth, and site temperature) were recorded. During reproductive surveys all of the above information was collected with the addition of sex, maturity and fecundity information.

A one stage progressive count roving creel survey was conducted each year during the winter fishing season from 1993 to1998. The summer fishery was monitored through an access point creel survey. Access point surveys were preformed in 1992, 1993, 1997 and 1998. In both seasonal surveys, fishers were monitored for catch and effort information. Individual fish attributes were measured during winter interviews. A separate roving survey was conducted during the summer to sample the catch. All fish were identified, enumerated and measured for fork length (to the nearest mm), weight (0.1 gram). An otolith and scales were taken for a sub-sample of the catch for aging purposes. In addition a maximum difference conjoint analysis (MDC) was conducted in conjunction with the summer creel surveys to seek out preferences toward possible management scenarios (Hunt unpublished data). The results of the MDC were used to help elucidate a range of management scenarios for simulation which would be acceptable to anglers. A standard annual sampling program is depicted in Fig. 2.

ANALYSES

Relative Abundance

The following statistics were the fundamental computations used in the stock assessment. They display the survey data in a summary form and are used as tools to determine relative abundance measures, survival and mortality estimates. Henceforth, we will denote catch as C and effort as f. Effort statistics were measured to assess whether reasonable "fixed effort" was applied during the survey. Ideally, each sampling occasion should use the same amount of effort and effort statistics will indicate whether the variation in effort is small. The following effort statistics are important to this analysis.

$$f = \Sigma f_i$$

where f is the total effort in the survey and f_i is the effort in sample I.

$$\bar{f} = \frac{\sum_{i}^{n} f_i}{n}$$

where $\bar{f}$ is the mean effort from n samples in the survey;

$$s = \sqrt{(s^2)}$$

where s is the standard deviation of effort and the square root of the variance with the variance being defined as;

$$s^2 = \frac{\sum_i^n (f_i - \bar{f})^2}{n-1}.$$

In order to compare the relative amounts of variation in populations having different means, the coefficient of variation, symbolized by CV, is used. This is simply the standard deviation expressed as a percentage of the mean (Sokal & Rohlf 1981);

$$CV = \frac{100 * s}{\bar{f}}.$$

Mean catch for a fixed effort is the most commonly reported statistic for abundance index surveys. The mean catch was calculated by;

$$\bar{C} = \frac{\sum_i^n C_i}{n}$$

where is the mean catch for n samples and C_i is the catch in sample I. Variance (s^2) of the catch was calculated by:

$$s^2 = \frac{\sum_i^n (C_i - \bar{C})^2}{n-1}.$$

Instead of computing the traditional standard deviation we computed the standard error. This is the estimate of the standard deviation of the mean we would expect were we to obtain a collection of means based on equal-sized samples of n items from the same population (Sokal & Rohfl 1981). Standard error (se) of the mean catch is denoted by :

$$se = \sqrt{\frac{s^2}{n}}.$$

The coefficient of variation is now defined as the standard error expressed as percentage of the mean and called relative standard error (RSE);

$$RSE = \frac{100 * se}{\overline{C}}.$$

Relative standard error (i.e., coefficient of variation of a mean) is used as the measure of precision for catch and relative standard deviation (i.e coefficient of variation of observations) is used as the measure of precision for effort. For mean catch, which is used as an index of fish abundance, we needed a standard error to assign a confidence interval on the estimates of abundance. For effort we were mainly interested in knowing how much it varied, a property expressed by the coefficient of variation of effort. Catch per unit of effort (CUE) is commonly used an index of abundance (Hoenig et al. 1987). CUE was calculated as the mean catch divided by the mean effort;

$$CUE = \frac{\overline{C}}{\overline{F}}$$

with a standard error;

$$se = \sqrt{\frac{s_C^2 + \overline{C^2} s_f^2 - 2\overline{C} s_{Cf}}{n\overline{f^2}}}$$

where s^2_c is the variance of the catch, s^2_f is the variance of the effort and s_{cf} is the standard deviation.

Population Number

The Schnabel method considers experiments where marking and recapture are done concurrently. The method requires that the population be constant, with no recruitment and no mortality (Ricker 1975). These assumptions were satisfied due to lake surveys taking place over a relatively short period of time. The following equation was used to calculate population number N;

$$N = \frac{\Sigma(C_t M_t)}{R + 1}$$

Where:

M_t total marked fish at large at the start of the *t*th day (or other interval);

M $\sum M_t$, total number marked.

C_t total sample taken on day *t*.

R_t number of recaptures in the sample C_t.

R $\sum R_t$, total recaptures during the experiment.

Approximate limits of confidence were obtained by considering R as a Poisson variable and given by the formula;

$$\frac{\Sigma(C_t M_t)}{R + 1.92 \pm 1.96\sqrt{R+1}}.$$

The Schnabel population estimates were carried out for nine ponds in Indian Bay Brook for the years 1995 to 1998. In order to safely ignore the probability of statistical bias, estimates were calculated only when recaptures numbered 4 or more (See Ricker 1975, p. 79, for further explanation).

Density and Biomass

Density and biomass estimates required relative abundance measures (Catch per net set) at age and Schnabel population estimates (N). Density was calculated as ;

$$d = \frac{N}{SA}$$

where: d = density, N is the total population number and SA is the surface area in hectares. Density was then partitioned by CUE-at-age from the fyke nets to provide a density at age. Biomass was then calculated as density-at-age (d_n) for each pond multiplied by the mean weight at age (mwt_n) for each pond and summed for all ages to obtain an estimate of fish biomass;

$$b = \sum(d_n mwt_n).$$

Mortality and Survival

Estimates of instantaneous survival rates and mortality rates were calculated from age composition (Ricker 1975). Estimates were preformed from age compositions observed in one year and through successive years. Heincke's (1913) estimate for mortality rate (A) was used. Number of individuals in the population was replaced with the relative abundance measure (CUE);

$$A = \frac{CUE_2}{\sum CUE}.$$

The youngest age used was 2. Since S = 1- A, the corresponding estimate of survival rate becomes;

$$S = \frac{\sum CUE - CUE_2}{\sum CUE}.$$

This methods involves the following assumptions about age groups when within year estimates are preformed; (1) mortality is the same for all ages: (2) mortality rate has been constant over time; (3) each group was recruited from the same initial abundance (or recruitment was small and random in nature); (4) each group was equally vulnerable to gear; (5) sample size was sufficiently large to represent the average population structure and (6) age was reliably determined. Assumptions (1) and (2) were avoided by comparing the abundance of the same cohort in successive years. Instantaneous rate of total mortality (Z) was calculated as;

$$Z = -\log_e S.$$

An estimate of natural mortality was obtained from the pooled catch curve (Fig. 7). Since young fish (i.e., < age 2) were not vulnerable to angling, the survival from age 1 to age 2 can be used to estimate natural mortality:

$$\frac{N_2}{N_1} = S_1 = e^{-M}.$$

To apply this method, we first had to adjust indices of abundance shown in Fig 7. To account for age-specific differences in fyke net vulnerability. Recapture-mark ratios indicated that vulnerability was constant for ages >= 2 and reached 70% of the maximum by age 1. We therefore calculated indices of abundance as:

$$N_i = \frac{C_i}{V_i}$$

where N_i is the index for age I, C_I is the age specific mean catch per net set, and V_I is the age-specific vulnerability (=0.7 for age 1 and 1.0 for older fish).

Age, Growth and Condition

Length at Age: The most common method of expressing age at length is von Bertalanffy, which gives a good descriptor of length and age;

$$L_t = L_\infty(1 - e^{-K(t-t_o)})$$

Where L_t is the mean length of the fish at age t (we use fork length in cm and age in years), L_∞ is the asymptotic length at infinite age, K is the growth coefficient (or the fraction by which the gap between Lt and L_∞ is closing each year (units yr^{-1}), and t_o is the extrapolated age at which L_t is zero. These parameter are important not only for predicting growth but for inputs into models which will be used to derive yields. Due to sampling problems the von Bertalanffy parameters could not be fitted by traditional non-empirical methods. The parameters would be unrealistic. The following method was used to allow an approximation of von Bertalanffy parameters (Payne et al. 1990). We constrained L_∞ to be some empirical measure of the maximum length of fish caught, and call it L_∞'. In addition we set t_o to zero, and called K, K′, and the von Bertalanffy equation was the rearranged into the form of a linear regression:

$$-\ln(1-\frac{L_t}{L'_\infty})=Kt-Kt_o$$

where

$$y=-\ln(1-\frac{L_t}{L'_\infty})$$

and

$$x=t$$

The slope of the line when forced through the origin (equivalent to setting t_o to zero) gave an estimate of K′. We applied this empirical method to our lake data set.

Weight- Length Relationship: The relationship between weight and length can be used to describe the relative condition of an individual fish in a population. Unlike age at length its utility is not affected by age interpretation bias. The only bias which remains is sampling gear bias. The relationship is defined by the from;

$$W=aL^b$$

where W is weight in grams, L = fork length in mm, and a and b are derived parameters. The parameters a and b were estimated for each lake for each year by least squares regression of $\log_{10}$ transformed mean weight- and length- at- age using the function;

$$\log W=\log a+b\log L.$$

Reproductive Potential

Three reproductive studies were carried out during the fall from 1996-1998. The length at maturity was expressed as the length at maturity when the 50% maturity level is reached (L_m). Estimates of the number eggs per female and the relative fecundity of brook trout for the watershed were derived. The relationship between length and fecundity can be described as;

$$F=ax^b$$

where F = fecundity (number of eggs) x= length, weight or age and a and b are derived parameters. The parameters a and b were estimated for each lake for each year by least squares regression of $\log_{10}$ transformed fecundity and length with the function:

$$\log F = \log a + b \log x.$$

Stock Recruitment Parameters

Schnabel population estimates and relative abundance estimates were used to calculate the female spawning biomass for brook trout in each pond. Total population number was multiplied by the relative abundance (CUE-at- age) to partition total population number by age. Biomass estimates for the population at each age were calculated by multiplying the mean weight at age by the population number at age. Female spawning biomass (FSB) is the product of ratio of female to males in the population, the biomass at age (B_n)and the percent maturity at age ($\%M_n$) and summed for a total estimate of FSB for the population. The following equation was used to calculate FSB;

$$FSB = \Sigma B_n x SR x \% M_n$$

Total egg production for a pond is simply given by;

$$TEP = FSB x f$$

where *f* is the relative fecundity expressed as mean number of eggs per kilogram. Egg survival to age 1 (α) was estimated by dividing the population estimate at age 1 ($N1_n$) in year n by the total egg production of spawning females in the pond in year n-1;

$$\alpha = \frac{N1_n}{TEP_{n-1}}.$$

Fisheries Statistics

Winter Creel: There were N days in the season, n days were sampled, and – *n* days were not surveyed. Of the – *n* days not surveyed, D were not surveyed because there was no fishing (e.g., major storm or weather too mild) and N-*n*-D days were not surveyed because of failures (e.g., snowmobile broken, sickness) i.e., an non-sampled day while there presumably was fishing activity. Where both winter seasonal effort for pond j is:

$$SeasonalEffort = \overline{f}_j \times (N-D)$$

where f_j is the average daily effort on fishable days on pond *j*.

We need f_j .where,

$$\overline{f}_j = \frac{\sum f_{jk}}{n}$$

So, we need f_{jk}:

$\overline{f}_{jk}$ = the estimated fishing effort on pond *j*, day *k*.
= $A_{jk} \times d$ angler hours.

where A_{jk} is the count of anglers on pond *j* on day *k* and *d* is the length of the fishing day surveyed d =9 hours). (Note: one count includes all interviews over one ``sweep" of a pond. Two or more counts is when the pond is revisited at different times of the day. If two or more counts were recorded the average of the counts for that day was used.) Catch per unit effort (CUE) was calculated by the following method which is the preferred method for a roving creel provided interviews of people fishing for short periods of time are excluded (Pollock et al. 1997);

$$\overline{CUE}_j = \frac{\sum \frac{c_{jl}}{e_{jl}}}{NI}$$

where NI is the number of interviews. We used the above equation to calculate CUE and eliminated all interviews for people fishing less than one half hour. The seasonal total catch for pond *j* is ;

$$C_j = \overline{f}_j (N-D) \overline{CUE}_j.$$

Summer Creel: The average daily effort f_{jd} was estimated by the sum of rods days RD_j for the season on pond *j* and divided by the total number of fishable days in the season FD to get a number rod days on pond *j* on an average day *d*; number of hours fished each day was the RD_j multiplied by the average estimated length of a fishing day (n) in hours;

$$\overline{f_{jd}} = \frac{\sum RD_j}{FD} n.$$

CUE was estimated by the method described below which is preferred for completed trip (access point) surveys and was used to estimate summer CUE (After Pollock et al. 1997) for pond *j*;

$$\overline{CUEj} = \frac{ADC}{\overline{f_{jd}}}$$

where CUE_j catch per unit effort in pond *j* is the ADC is the average daily catch divided by the average daily effort in pond *j* on an average day *d*. The Seasonal Catch was the product of the average daily effort, the average daily CUE and the total number of fishing days;

$$SC = \overline{f_{jd}} \times \overline{CUE_{jd}} \times FD.$$

Seasonal catch, harvest, effort and catch per unit of effort (CUE) were expressed on a per hectare basis for each pond for all years combined. Seasonal harvest and harvest weight per unit effort (HWUE) was also expressed by multiplying the mean weight of the fish caught.

Release rates for brook trout were reported as a mean annual release rate for the period 1995-1998 for both the winter and summer fisheries. Release rate was calculated by the following equation;

$$RR = \frac{NR}{NC}$$

where RR is the release rate, NR is the number released and NC is the number captured.

RESULTS AND DISCUSSION

Age and Growth

We applied an empirical method to estimate von Bertalanffy parameters from a 13 pond data set consisting of fork length-at-age. The 3 largest fish in the population sampled was used as an absolute minimum to estimate L_∞' for each pond. Total number of fish used to estimate L_∞' for all ponds combined was n = 39. Mean lengths between the ages of 2 and 7 were used to estimate K'. All aging was done with otoliths. Parameter values describing brook trout mean annual growth for all ponds are listed in Table 3. Mean values for L_∞' was set at 405 mm and K' was set at 0.37. The following equation represents the curve (Fig.3) describing brook trout mean annual growth for 13 pond populations;

$$L_t = 405(1 - e^{-0.37(t)})$$

K' estimates for the period 1995-1998 varied between ponds with a minimum of 0.18 for Little Bear Cave Pond and a maximum of 0.50 in both Alley's and Big Bear Cave Pond. L_∞' Also varied considerably between ponds ranging from 617 in Little Bear Cave Pond to 310 mm in Big Bear Cave Pond. For the purposes of this investigation we have chosen to express the mean length-at-age relationship depicting all ponds over the sampling period. The mean values of L_∞' and K' will be used in subsequent modelling exercises. Unfortunately no comparisons can be made with non-empirically derived estimates of von Bertalanffy parameters because sampling problems occurred. The von Bertalanffy parameters could not be fitted by traditional non-empirical methods (e.g. Ford-Walford Plot) due to the under-representation of younger ages and the absence of any relevant independent data sets. This empirical method should only be viewed as an intermediate solution until all ages are fully incorporated into the description of growth.

We derived a standard equation by least squares linear regression of $\log_{10}$ transformed mean weight and length from fyke net catches. We propose the weight length relationship (Fig. 4) is represented by the following equation;

$$W = 0.0092L^{3.05}$$

Weight-length relationship parameters b = 3.05 (gm/cm) and a = 0.0092 are mean values for all ponds surveyed from 1995 to1998. Parameter b varied during the sampling period from 2.77 for Little Wings Pond to a maximum of 3.20 for Big Wings Pond. Parameter a also varied considerably between ponds ranging from 0.0062 in Big Wings Pond to a minimum of 0.022 in Little Wings Pond. All values are listed in Table 3. For the modelling exercise we have chosen to express the mean weight length relationship for all ponds over the sampling period.

Abundance

Relative abundance was expressed as mean catch per net set (CUE) of brook trout from the spring fyke net catches. Estimates calculated for the total population and CUE-at-age for all ponds combined for each year are depicted in Fig. 5 and Table 4. In addition estimates of CUE-at-age for all lakes in all years sampled is illustrated in Fig. 6. A picture of CUE-at-age for all ponds and years combined is depicted in Fig. 7 and Table 5. The pooled catch curve shown in Fig. 7 was used in subsequent analysis to determine instantaneous rate of natural mortality after re-scaling for vulnerability. Schnabel population estimates were completed on a total of 9 lakes some with multiple year estimates. Schnabel population estimates ranged from 1,938 to 21, 618 fish (Table 4). Estimates of population density ranged from 3.6 to 179 fish/ha on Little Bear Cave Pond and Skipper's Pond respectively (Table 4). Biomass ranged from 0.43 kg/ha to 15.55 kg/ha in Indian Bay Pond and Skipper's Pond respectively.

Mortality and Survival

Total mortality and survival estimates from 13 lake populations using an age interval from age 2 to age 6 ranged from 0.31 to 0.72 (mean 0.59) and from 0.23 to 0.69 (mean 0.41) respectively. Estimates were made with CUE-at-age data within the same year. Successive years estimates using CUE-at-age resulted in total mortality and survival estimates for the same 13 populations ranging from 0.11 to 0.69 (mean 0.44) and 0.31 to 0.89 (mean 0.52) respectively (Table 6). We obtain an estimate of 0.67 for the survival from age 1 to age 2, implying a natural mortality rate, M=0.45.

Reproductive Potential

Mean relative fecundity for all ponds was estimated as 2539.69 eggs with a range of 2398 to 2634 eggs per kilogram in Four Mile Pond and Alleys Pond respectively. A summary of relative fecundity measures are listed in Table 7 . The relationship between length and fecundity is illustrated in fig 9 a & b. Fall fyke netting surveys revealed a sex ratio of approximately 1 to 1. In addition maturity was recorded for all fish surveyed. Length at maturity was calculated from fall fyke netting surveys in ponds from a 1998 survey. The length at 50% maturity was 22.5 cm , length at 5% was 15.0 cm and length at 95% maturity was 30.0 cm (fig 10). These results should be viewed as a description of maturity not a complete analysis. More years of data are needed to refine estimates of these parameters. Values for relative fecundity, sex ratio and length at maturity were used in subsequent calculations of female spawning biomass and total egg production.

Stock Recruitment Parameters:

Female spawning biomass and total egg production and egg to age 1 survival estimates for all pond surveyed (n=5) are given in Table 8. Mean female spawning biomass was 0.66 kg/ha with a range of 0.21

kg/ha in Little Bear Cave in 1994 to 1.30 kg/ha in Little Bear Cave in 1993. Total egg production ranged from 355 egg/ha in Indian Bay Big Pond to 3292 eggs/ha in Little Bear Cave Pond 1993 with mean for all ponds surveyed of 1677 eggs/ha. Egg to age 1 survival ranged from 0.0004 in Little Bear Cave 1993-1994 to a maximum survival of 0.0130 in Fourth Pond.

Variation in egg survival is negatively correlated with spawner biomass. Although the result is not significant (R^2 = 0.34, p=0.13, n=8) statistical power is very low given the small sample size. The regression implies that maximum egg survival (i.e., at low densities) is 0.007. That is 7 in 1000 eggs survive to become age 1 fish. We used this estimate of maximum egg survival and average fecundity (2540 eggs/kg) to constrain the initial slope of the stock-recruitment relationship (Fig 8). Using the Shepherd function (Shepherd 1982), stock-recruitment can be described as;

$$N_i = \frac{2540 * 0.007 * FSB}{(1 + (\frac{FSB}{1.5})^{\beta})}$$

where N1 is the number of age 1 recruits, αmax (0.007) is the maximum egg survival, fmax (2540) is the maximum fecundity, FSB is the female spawner biomass, Bo (1.5) is a parameter related to carrying capacity and β is a shape parameter. We also constrained the shape parameter (β = 1) which leads to an asymptotic relationship. Given these constraints, an estimate of carrying capacity parameter is in the order of (i.e., Bo = 1.5). This value implies that density-dependent effects reduce reproductive efficiency (e.g. fecundity x egg survival) by one-half the maximum value when spawner biomass reaches 1 kg/ha.

Fisheries Statistics:

Combined figures for winter and summer gave mean annual yield of 0.31 kg/ha and a mean annual effort of 2.67 angler hours/ha. The mean annual CUE was 1.33 fish/hr and HWUE was 0.33 kg/hr. There was considerable variation between ponds. The mean annal summer effort ranged from 40 in Indian Bay Pond to 4068 in Indian Bay Big Pond. Yield varied from 0.001 to 0.49 kg/ha and mean annual effort ranged from 0.004 to 4.58 angler hrs/ha. Winter was less variable but still exhibited a wide range of values of mean annual effort, from 0.09 to 1.56 angler hr/ha. The CUE and the HWUE varied from 0.04 to 0.45 kg/ha. All fisheries statistics are displayed in tables 9 through 12. Fig 11 is a scatter plot displaying the relationship between yield (kg/hectares) and fishing effort (angler hours/hectare) for the brook trout recreational fishery in Indian Bay Brook Watershed. Fig 12 shows the pooled angled catch curve which was used to estimate the length at full vulnerability. Length was set at 20 cm, 15 cm and 25 cm for 5, 50 and 95 % vulnerability respectively.

CONCLUSIONS

The following report provided a summary description of the population dynamics and recreational fisheries of brook trout in Indian Bay Brook for the period 1995-1998. The summary is based on pooled data from 14 ponds and should be treated as a representative picture. We used the combined data from all ponds to develop our model. Although some differences exist among ponds, we do not have sufficient data to argue that these differences are related to inherent properties of the ponds. Given the dynamics of how populations respond to stress, these differences may reflect different stages of response to changes in fishing pressure.

The monitoring and research program is ongoing and with additional years of data our understanding of brook trout life history and how fisheries affect them will become clearer. The goal of the program was to provide defensible scientific information upon which to base management options. We feel that the program has met its objective thus far. Table 13 lists the parameters which were used in the modelling exercises documented in Lester et al (1999). The data used to model has weaknesses due to the uncertainty of several parameters. These uncertainties affect estimates of key reference values (e.g. maximum yield, effort at maximum yield, effort at extinction) and the diagnosis of fishery status. They should not affect conclusions regarding the relative effectiveness of different management actions.

REFERENCES CITED

Casselman, J.M., Barnes L., and Brown D.M. 1995. Methodology for producing cellulose acetate replicas of sagittal otolith sections (prepared manuscript).

Damman, A.H.W. 1983 An ecological subdivision of the island of Newfoundland. Monographiae Biologicae 48: 163-206.

DFO (1995) Surveys of recreational fishing in Canada. Statistical Services Economic and Policy Analysis Directorate, Department of Fisheries and Oceans. Economic and Commercial Analysis, Report No. 154.

de Graaf , D.A. 1983 Detailed Investigations of brook trout and Arctic charr populations in Cat Arm Lake. LGL Limited Report to Newfoundland and Labrador Hydro 65p.

Fowlow, P.S., Hoenig, J.M., and M.C. van Zyll de Jong 1997. Indian Bay Watershed Roving Creel Survey-Seasonal Catch and Effort Analyses and Estimates. DFO Atlantic Fisheries Research Document 96/11

Heincke, F 1913. Investigations on plaice. Rapp. P.V. Reun. Cons. Perm. Int. Explor. Mer. 16. 67 p.

Hoenig, J.M., D.M. Heisey, W.D. Lawing, and D.H. Schupp. 1987. An indirect rapid methods approach to assessment. Can. J. Fish. Aquat. Sci. 44(Suppl. 2):324-338.

Knoechel R. and P.M. Ryan 1994. Optimization of fish census design: An empirical approach based on long-term Schnabel estimates fro brook trout (Salvelnius fontinalis) populations in Newfoundland Lakes.Verh. Internat. Verein. Limnol. 25: 2074-2079.

Lester N.P. , Petzold, M.M., Dunlop, W.I., Monroe, B.P., Orsatti, S.D., Schaner, T. And D.R. Wood (1991) Sampling Ontario Lake Trout Stocks: Issues and Standards: Lake trout synthesis. Ont. Min. of Nat. Resour. Toronto. 117p.

Lester, N.P. , R.M. Korver, M.C. van Zyll de Jong, W. Norris and B. Wicks (1999) A Model for Managing Exploitation of Brook trout in Indian Bay, Newfoundland. DFO Can. Stock Assess. Sec. Res. Doc. 99/98.

OMNR 1983 Field methods manual. Ontario Ministry of Natural Resources.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. int. Explor. Mer. 39(2): 175-192.

Payne, N.R., R.M. Korver, D.S. MacLennan, S.J. Nepszy, B.J. Shuter and E.R. Thomas 1990 The harvest potential and dynamics of lake trout populations in Ontario, Lake Trout Synthesis Population Dynamics Working Group Report Ontario Ministry of Natural Resources, Toronto Ont.

Pollock, K.H., J.M. Hoenig, C.M. Jones and C. Greene 1997. Catch rates estimation for roving and access point surveys of anglers. N. Am. J., Fish. Manag. 17: 11-20

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191, Fisheries Research Board of Canada, Ottawa, Canada.

Ryan, P.M. and R. Knoechel 1994. Lake use by brook trout, Salvelnius fontinalis, in insular Newfoundland, Canada. Verh. Internat. Verein. Limnol. 25: 2068-2073.

Ryan, P.M. 1984. Fyke net catches as indices of the abundance of brook trout Salvelinus fontinalis and Atlantic salmon salmo salar CFAS 41:377-380.

Shepard, J.G. 1982. A versatile new stock recriutment curve relationship for fisheries and the construction of sustainable yield curves. J. Cons. Int. Explor. Mer. 40:67-75.

Scott W.B. and E.J. Crossman 1973. Freshwater fishes of Canada. Fish. Res. Board Can. Bull 184. 966p.

Sokal, R.R. and F.J. Rohfl. 1981. Biometry. W.H. Freeman & Co., New York.

Wiseman, R.J. (1969) Some aspects of the biology of the speckled trout, Salvelinus fontinalis (Mitchill) 1815, in the waters of insular Newfoundland. M.Sc. Thesis, Department of Biology, Memorial University of Newfoundland.

Table 1. Location , physical and chemical variables measured in the Indian Bay Brook ponds. Latitude, Longitude, Surface Area (SA) in hectares. Mean Depth (MD) in meters, and Elevation (EL) in meters. Shoreline Development (SD) no units. Perimeter (PER) and Distance to the coastline (DC) in kilometers. Total dissolved solids (TDS) and Conductivity (CON) is in units of microsiemens per centimeter at 25°C.

Pond	Latitude	Longitude	SA	MD	SD	EL	PER	DC	Cond	TDS
Alley's Pond	49°07′04″	54°07′48″	408	4.7	1.05	45	7.5	21	34.2	31.64
Back-up Pond	49°04′00″	54°10′28″	964	3.4	1.55	45	17	21.4	30.26	28.81
Big Bear Cave Pond	49°07′00″	53°59′00″	512	9.3	1.5	60	12	12.4	35.9	32.8
Big Wings Pond	49°00′30″	54°07′15″	1088	10.4	1.84	45	21.5	14.2	42.8	37.8
First Pond	49°02′45″	54°00′13″	559	5.5	2.03	30	17	9	40	35.8
Forked Pond	49°08′28″	54°01′22″	570	6.7	1.66	76	14	15.6	55	46.6
Four Mile Pond	49°08′21″	54°01′25″	417	6.4	1.72	60	12.5	11.7	31.7	29.84
Indian Bay Pond	49°05′40″	54°18′25″	967	5.6	2.16	45	23.8	25.7	46.4	40.43
Indian Bay Big Pond	49°04′00″	54°07′00″	1094	5	2.35	45	27.6	17.6	33	30.78
Little Bear Cave Pond	49°05′30″	54°05′00″	200	4.3	1.4	45	7	15.5	32.8	30.64
Little Wings Pond	49°00′30″	54°12′00″	138	3.1	1.84	60	7.8	18.4	55	46.6
Mocassin Pond	49°08′20″	54°04′28″	500	6.3	1.51	76	12	18.3	35.6	32.65
Skipper's Pond	49°05′30″	54°07′30″	116	2.91	1.75	45	6.7	18.1	37.8	34.24
Southern Pond	49°01′43″	54°10′15″	365	4.5	1.57	60	10.6	18.7	52.5	44.82
Third Pond	49°03′00″	54°12′00″	272	3	1.54	45	9	22.2	41	36.54

Table 2. Capture methodological standards and guidelines

Parameter	Target	Acceptable Range
Season	May 15- July 15	temperature window (9-19 °C)
Sampling size	10-140 net sets	Relative standard error for the catch per net set of < 20%.
Set duration	24 hrs.	23 - 25 hrs.
Gear	1.5 m fyke net	standardized dimensions
Net separation	200 m	> 200 m
Reuse of sites	none	at least 48 hrs
Lead length in water	30 m	25 - 30 m
Lead-shore distance	0.00	0 - 3 m
Depth with end of lead	0-1.5 m	0 - 2 m
Lead angle from shore	90 degrees	70-90 degrees

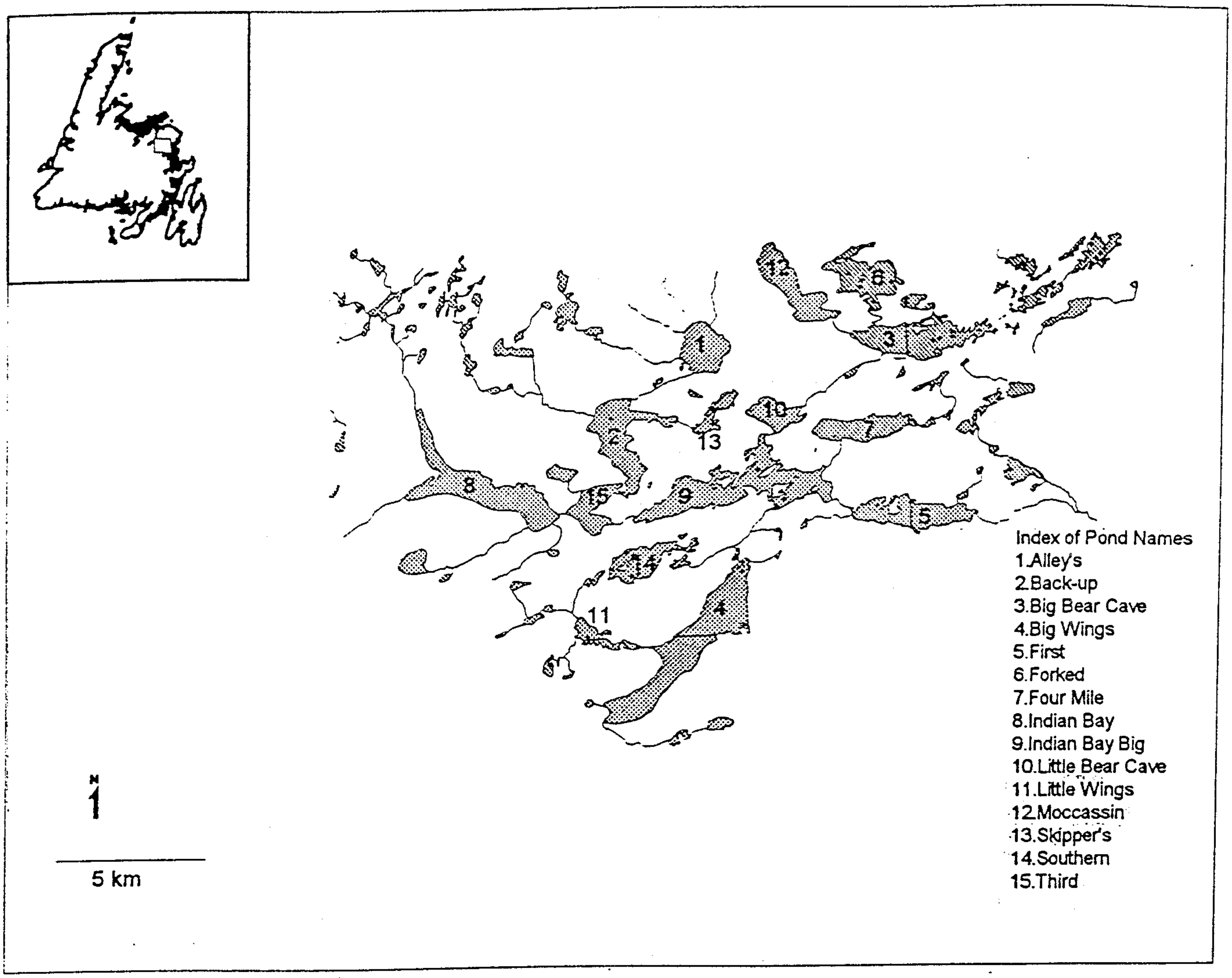


Fig. 1. Indian Bay Brook watershed including study lakes.

SEASON	SPORT FISHING	INDEX NETTING
Winter	EH/ CS	
Spring/ Summer	EH/CS/DC	CS/TAG
FALL		CS/RS/(TAG)

Fig 2. Sampling framework for lake assessments identifying the type of sampling required each season of a typical year. EH - effort/harvest, CS - catch sampling, DC - discrete choice survey, RS - reproductive survey, TAG - apply/recapture tags.

Table 3. Growth parameters including; (1) parameter values "a" and "b" for the brook trout (log_{10} transformed) weight-length function; and, (2) von Bertalanffy parameters (K' and L∞') from non-linear estimation. Parameters are listed for all 14 Indian Bay ponds (mean values for period 1995-1998) and summary statistics for all ponds combined.

Pond	Weight-length relation			von Bertalanffy non-linear estimates	
	b (gm/cm)	a	r^2	K'	L∞'
Alley's	3.04	0.0097	0.923	0.58	394
Big Bear Cave	3.1	0.0089	0.991	0.5	310
Back-up	3.07	0.0079	0.979	0.47	394
Big Wings	3.18	0.0062	0.957	0.43	440
Four Mile	2.98	0.011	0.957	0.28	425
Indian Bay	3.1	0.0081	0.967	0.32	429
Little Bear Cave	3.11	0.0076	0.977	0.18	617
Little Wing's	2.77	0.022	0.944	0.43	361
Mocassin	3.05	0.0092	0.987	0.27	440
Skipper's	3.06	0.0081	0.906	0.35	383
Indian Bay Big	3.1	0.0078	0.969	0.33	423
Southern	3.05	0.0097	0.94	0.38	410
Third	2.99	0.0106	0.95	0.37	408
All Ponds Combined					
Mean	3.049	0.0092	0.963	0.37	405
Minimum	2.77	0.0062	-	0.18	310
Maximum	3.18	0.022	-	0.58	617

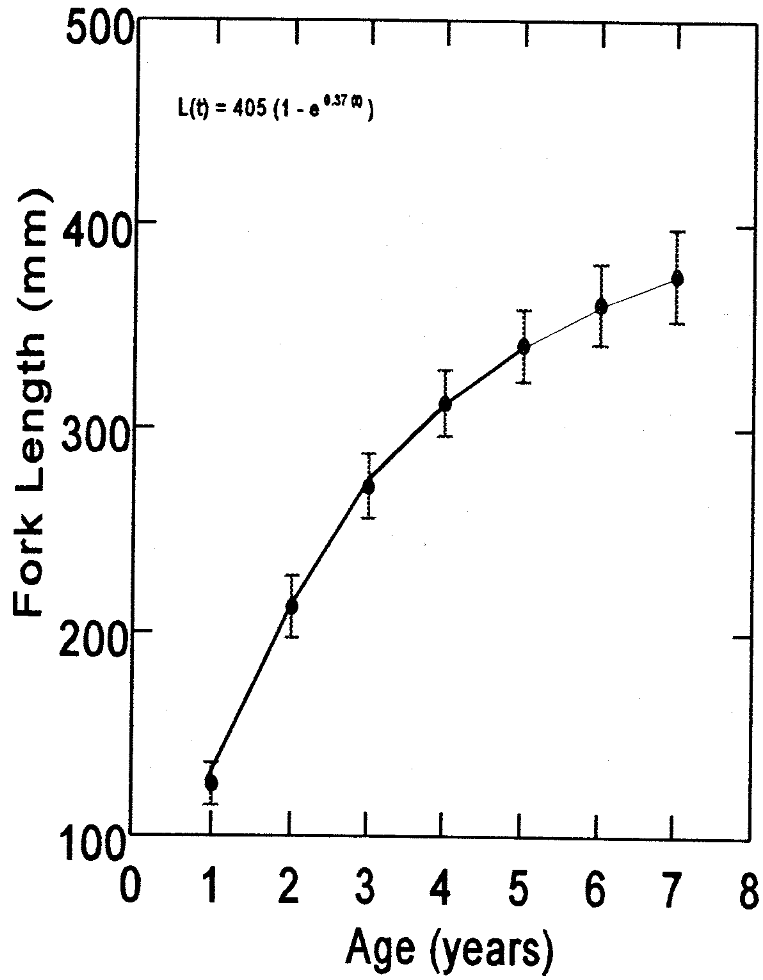
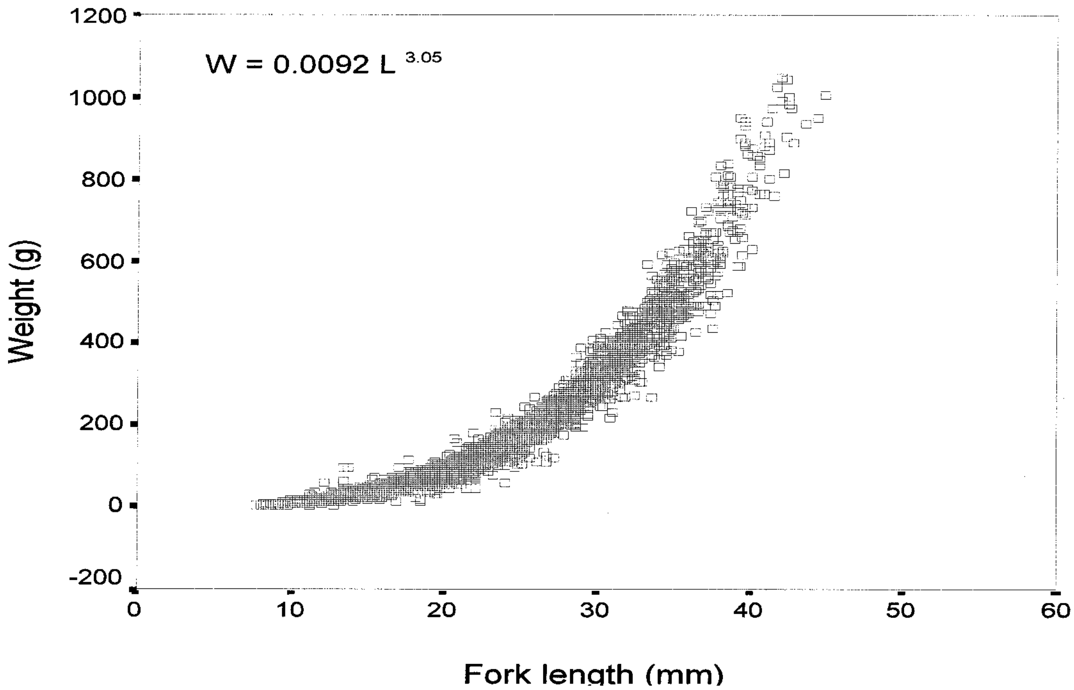


Fig 3. Summary of estimated fork length(mm)-at-age for brook trout in 13 Indian Bay Ponds. Von Bertalanffy parameters (L∞' and K') were calculated for each lake. The mean and 95% confidence intervals were found for the resulting lengths estimated for each age. Mean values of L∞' and K' from all ponds were used to generate the standard equation used in further analysis shown in top left hand corner.



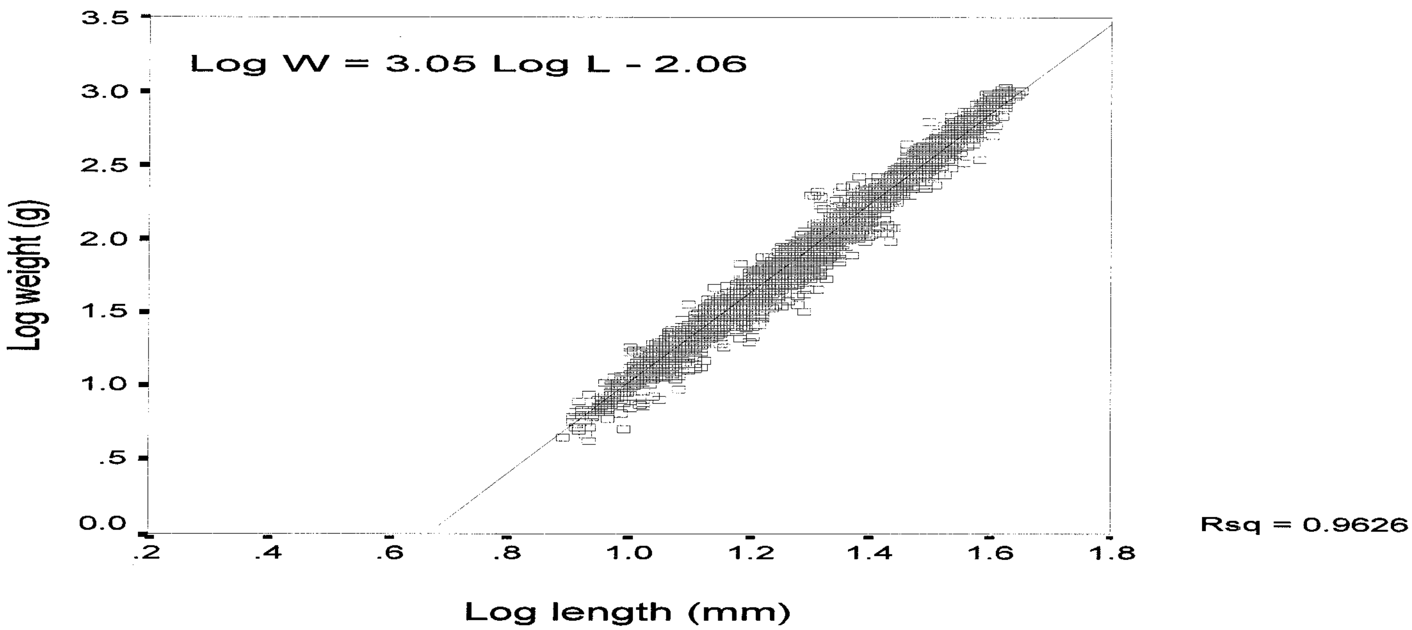


Fig 4 : a) Weight-length relationship for brook trout drawn from 13 lakes populations. b) Logweight-Loglength relationship for brook trout drawn from13 Indian Bay lakes. Equation are shown in the upper left hand corners.

Table 4 . Relative abundance (Catch per net set), Schnabel population estimates (total population number, density and biomass estimates) for brook trout populations in 13 ponds of the Indian Bay Brook for the period 1995-1998. RSE = relative standard error of catch per net set; UCL = upper confidence limit and LCL = the lower confidence limit of the Schnabel population estimate N; P_{age1} = Proportion of catch that are age 1 fish.

Pond	Year	Net Sets	Relative Abundance Estimates			Schnabel Population Estimates				
			Total	RSE	P_{age1}	N	UCL	LCL	Density Number/h	Biomass kg/h
Alleys	95	20	14.75	36.00	0.39					
	96	16	12.88	19.50	0.24					
	97	20	89.20	23.60	0.68	15411	18596	12988	37.77	1.85
	98	20	17.80	16.60	0.37	5136	10423	3067	12.59	1.00
Big Bear Cave	95	20	10.95	28.70	0.44					
	96	20	1.80	37.10	0.25					
	98	16	2.56	33.20	0.37					
Back Up	96	20	10.90	23.30	0.28					
	97	20	34.40	19.80	0.44	13574	21618	9065	14.08	1.06
	98	8	31.13	17.90	0.12					
Big Wings	98	20	7.30	28.20	0.42					
Four Mile	95	140	3.91	12.70	0.28	9973	21121	5826	23.09	1.21
	96	90	0.99	23.50	0.35					
	97	137	8.47	14.10	0.53	4373	4730	4022	10.48	0.62
	98	56	1.45	17.20	0.28					
Indian Bay	96	20	0.85	35.50	0.06					
	97	20	20.80	22.10	0.50	4229	6625	2940	4.37	0.43
	98	20	22.00	19.20	0.55	3483	14007	2930	3.60	0.54
Little Bear	95	112	1.52	14.80	0.34	1078	3506	532	5.39	0.55
	96	100	3.78	14.70	0.16	1829	2664	1336	9.14	1.59
	97	138	3.59	17.00	0.45	1542	1938	1258	7.71	0.59
	98	70	1.46	18.90	0.28					
Little Wings	98	10	24.20	19.60	0.20					
Mocassin	96	20	4.45	32.90	0.52					
	98	12	2.83	20.80	0.65					
Skippers	96	16	4.06	34.50	0.22					
	97	20	19.45	23.90	0.34	20765	50895	10508	179	15.55
	98	16	25.38	27.80	0.46					

Table 4	Cont'd									
Indian Bay Big	95	99	1.76	18.40	0.22					
	96	100	2.39	19.00	0.13					
	97	140	3.37	14.50	0.13	5040	7886	3507	4.61	2.35
	98	84	2.18	15.20	0.16					
Southern	95	16	1.50	34.40	0.38					
	96	20	0.50	49.20	0.00					
	97	20	17.40	28.50	0.68	3057	4767	2085	8.37	0.45
	98	8	13.88	24.60	0.24					
Third	95	130	7.27	11.90	0.35	7540	10525	5675	27.72	1.56
	96	100	7.48	12.90	0.24	3827	5021	3017	14.06	1.32
	97	20	4.00	44.90	0.14					
	98	42	7.12	51.20	0.41					

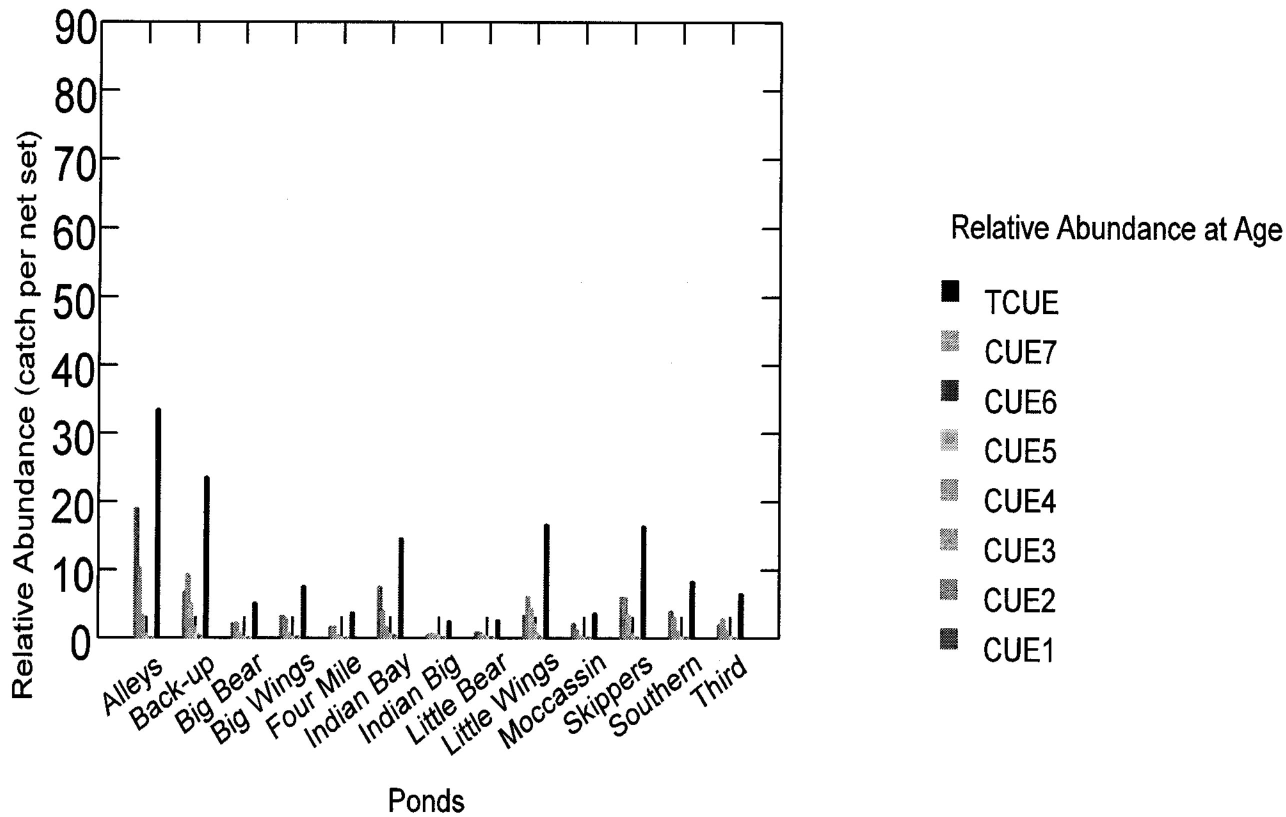


Fig 5. Estimates of relative abundance expressed as catch per net set (CPNS) of brook trout for each age and total population for 13 ponds in Indian Bay Brook for the years 1995,1996,1997,1998.

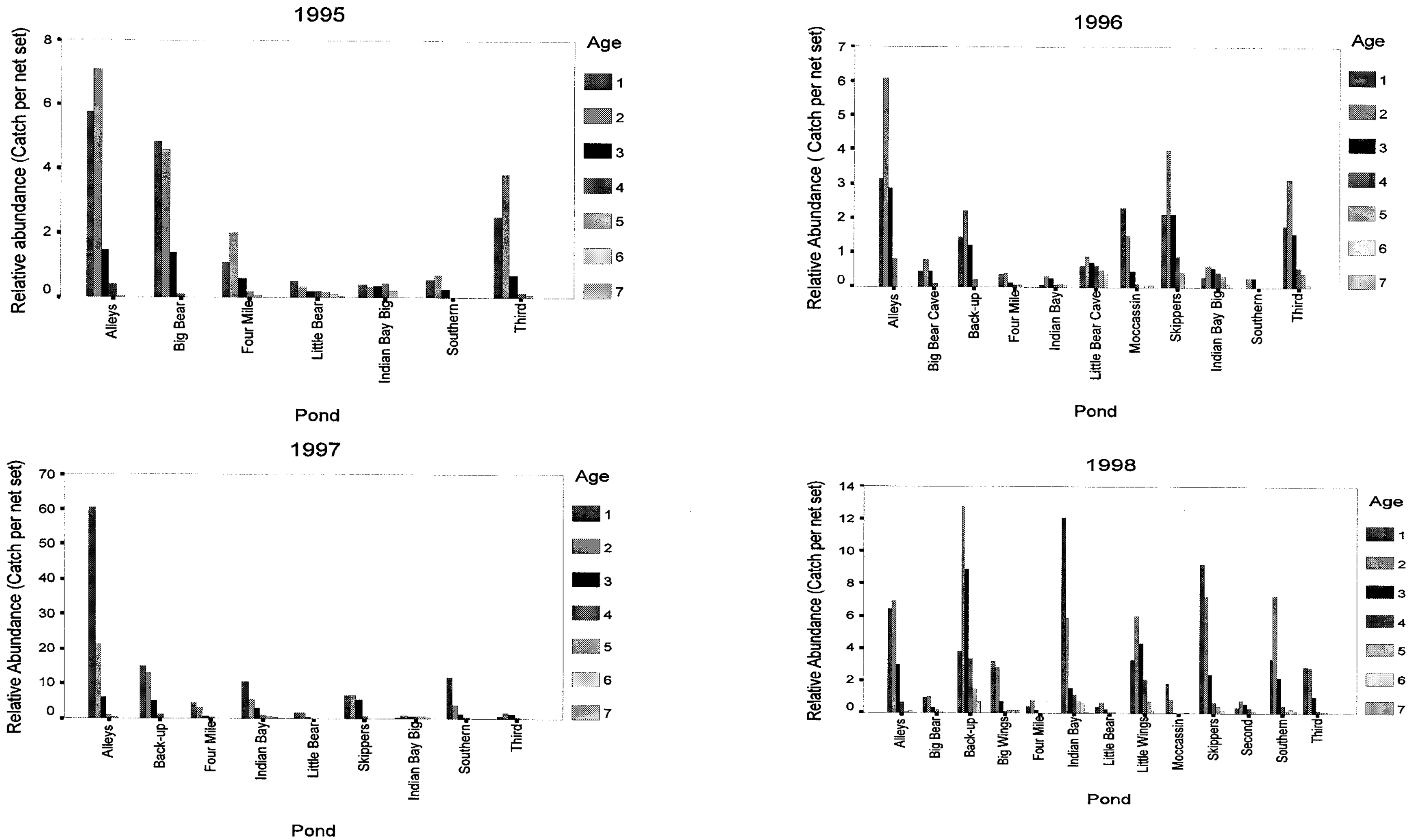


Fig 6. Relative abundance (catch per net set) at age of brook trout for 13 ponds in Indian Bay during the period 1995-1998.

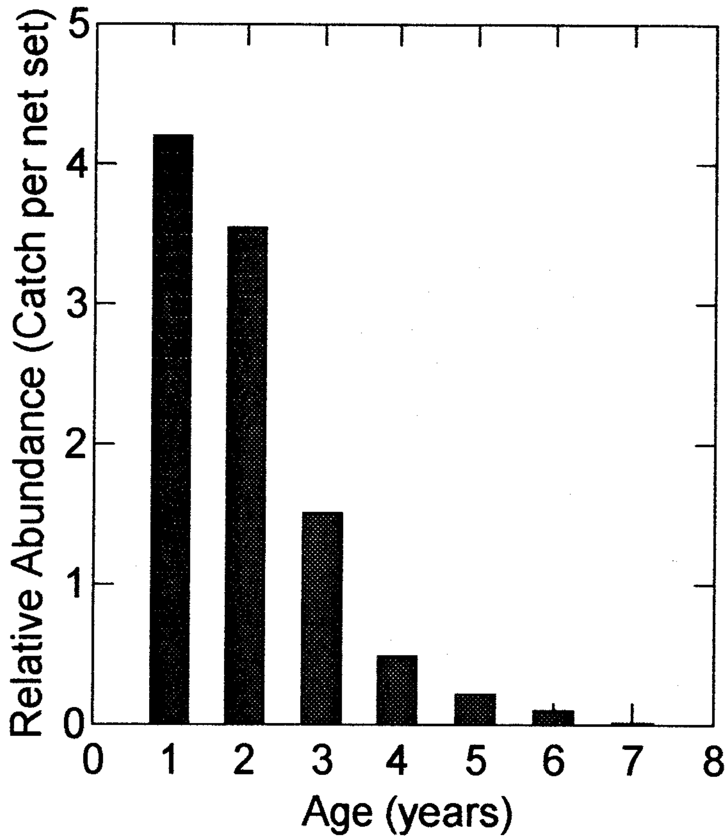


Fig 7. Pooled catch curve describing relative abundance estimates (Catch per net set) at age of brook trout from 13 ponds in Indian Bay Brook for the period 1995-1998.

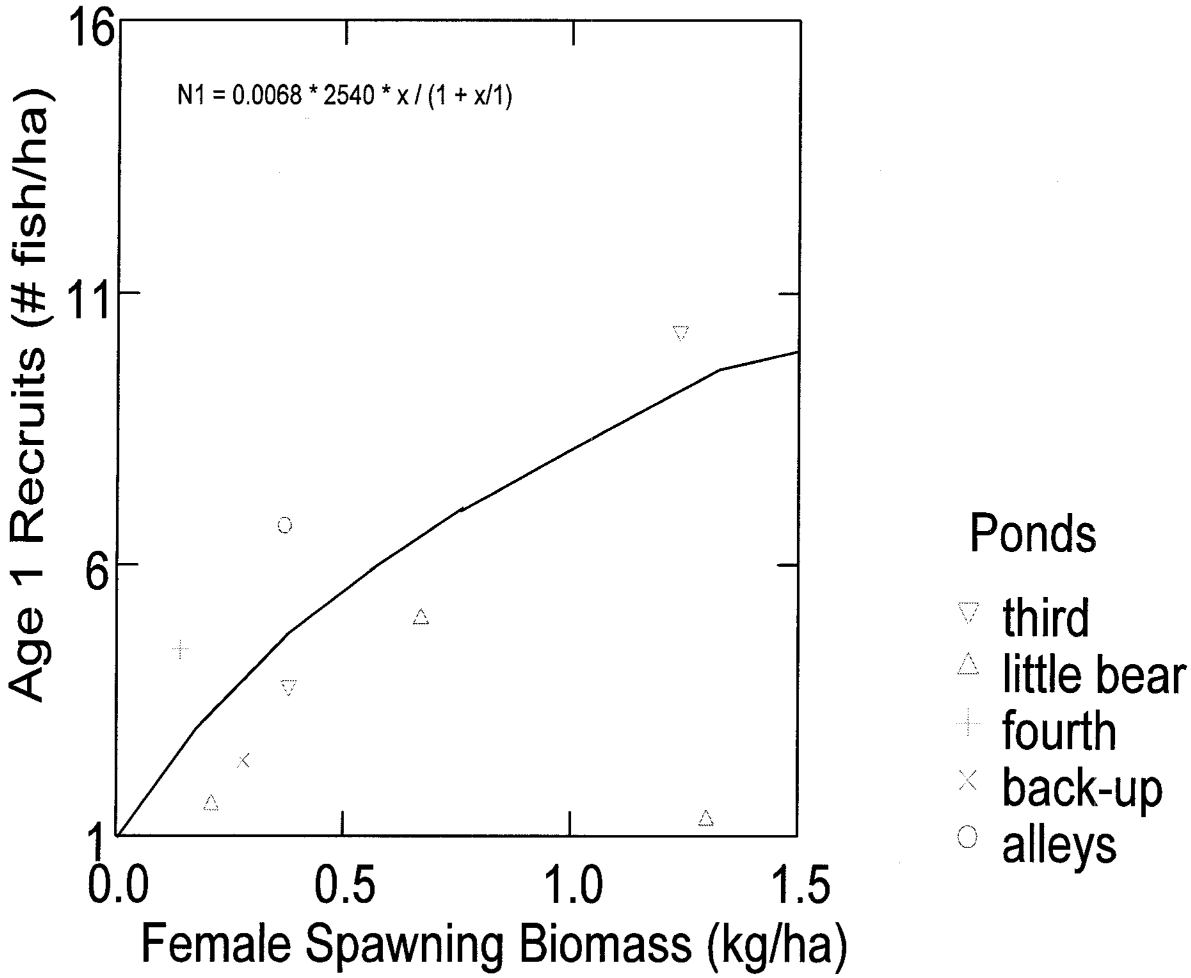


Fig. 8 Relation between abundance at age 1 and the female spawning biomass. The solid line is a Shepherd stock-recruitment relation for Indian Bay Brook trout. The equation in the upper left hand corner describes the relationship where n1 is age 1 recruits and x is female spawning biomass.

Table 5. Relative abundance (catch per net set) of brook trout in 13 ponds in Indian Bay Brook. All estimates come from spring fyke littoral index netting and are pooled for years 1995-1998. Included are summary statistics for all ponds combined.

Ponds	Relative Abundance (Catch per net set-by -age)							
	1	2	3	4	5	6	7	Total
Alley's	18.95	10.31	3.35	0.73	0.08	0.05	0.00	33.48
Big Bear Cave	2.08	2.13	0.74	0.13	0.02	0.00	0.00	5.10
Back-up	6.77	9.29	5.06	1.60	0.55	0.27	0.00	23.54
Big Wings	3.20	2.85	0.75	0.15	0.20	0.20	0.20	7.55
Four Mile	2.17	1.98	0.54	0.16	0.09	0.06	0.06	4.96
Indian Bay	7.50	3.90	1.55	0.71	0.46	0.36	0.03	14.54
Little Bear Cave	1.05	1.27	0.48	0.35	0.23	0.13	0.02	3.52
Little Wing's	3.30	6.00	4.30	2.10	0.70	0.20	0.00	16.60
Mocassin	2.07	1.17	0.27	0.05	0.00	0.07	0.03	3.64
Skipper's	5.95	5.92	3.31	0.77	0.33	0.06	0.00	16.35
Indian Bay Big	0.59	0.98	0.66	0.44	0.31	0.08	0.07	3.07
Southern	3.95	2.97	1.02	0.20	0.07	0.08	0.03	8.31
Third	1.95	3.07	1.35	0.36	0.18	0.06	0.00	6.97
All Ponds Combined								
Mean	4.20	3.54	1.51	0.49	0.21	0.10	0.01	10.06
SE	1.27	0.56	0.25	0.08	0.04	0.02	0.006	1.99
Minimum	0.59	0.98	0.66	0.13	0.02	0.00	0.00	3.07
Maximum	18.95	10.31	4.30	2.10	0.70	0.36	0.20	33.48

Table 6 . Total instantaneous mortality rates (Z), absolute survival (S), absolute mortality estimates (A). Mean values for each pond combining all years are displayed. Both within year and successive year estimates are given

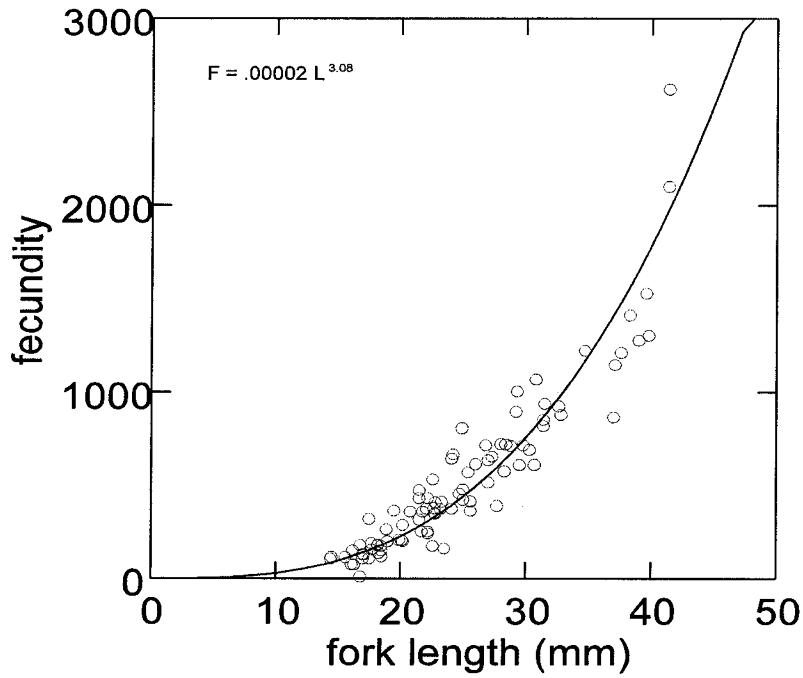
Ponds	Within Year			Successive Years		
	A	S	Z	A	S	Z
Alley's	0.69	0.30	1.20	0.47	0.53	0.64
Big Bear Cave	0.65	0.35	1.04			
Back-up	0.57	0.42	0.87			
Big Wings	0.65	0.35	1.04			
Four Mile	0.72	0.28	1.27	0.69	0.31	1.98
Indian Bay	0.51	0.49	0.71			
Little Bear Cave	0.49	0.51	0.67	0.53	0.47	0.82
Little Wing's	0.45	0.55	0.6			
Mocassin	0.76	0.23	1.47			
Skipper's	0.57	0.43	0.84			
Indian Bay Big	0.31	0.69	0.37	0.41	0.59	0.58
Southern	0.65	0.35	1.04	0.11	0.89	0.12
Third	0.61	0.38	0.97	0.69	0.31	1.19
All Ponds Combined						
Mean	0.59	0.41	0.96	0.44	0.52	0.89
Minimum	0.31	0.23	0.37	0.11	0.31	0.12
Maximum	0.72	0.69	1.47	0.69	0.89	1.98

Table 7 . Estimates of relative fecundity (eggs/kg) for brook trout from 3 Indian Bay Ponds. Mean Annual estimates for al ponds combined are given.

Lake	N	Min	Max	Mean	S.E.
Four Mile	28	1216	4214	2398	108
Alleys	63	1424	3810	2634	76
Southern	25	1002	4692	2473	165
All Ponds	117	1002	4692	2540	60

Table 8 . Pond estimate of $N1_n$ recruits, total egg production TEP_{n-1}, female spawning biomass (FSB) and egg to age 1 survival (α) .

Lake	Year	$C1/V1_n$ #/ha	TEP_{n-1} #/ha	FSB (kg) kg/ha	α
Alleys	96-97	6.73	944.44	0.37	0.0071
Back-up	96-97	2.39	715.04	0.28	0.0033
Fourth	96-97	4.44	354.90	0.14	0.0130
Little Bear	93-94	1.30	3292.06	1.30	0.0004
Little Bear	94-95	1.57	541.13	0.21	0.0030
Little Bear	95-96	5.00	1702.60	0.67	0.0030
Third	93-94	10.30	3148.26	1.24	0.0030
Third	94-95	3.76	958.88	0.38	0.0040
All Ponds					
Mean		4.42	1677.02	0.66	0.0046
S.E.		1.05	671.07	0.26	0.0014
Minimum		1.30	354.9	0.14	0.0004
Maximum		10.30	3292.06	1.24	0.0130



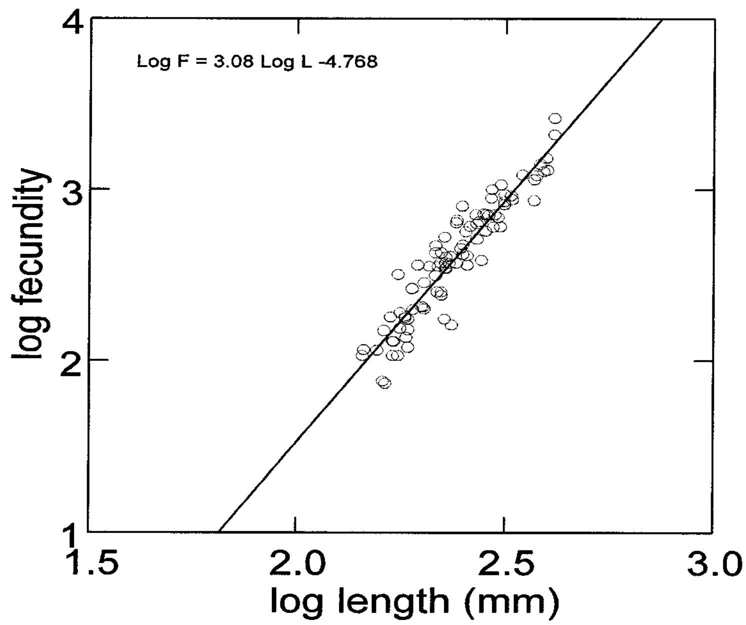


Fig.9. Fecundity-length relationship from brook trout drawn from spawning survey data from 1998, log fecundity- log length is also shown. Equations in the top left hand corner of the graph show equation

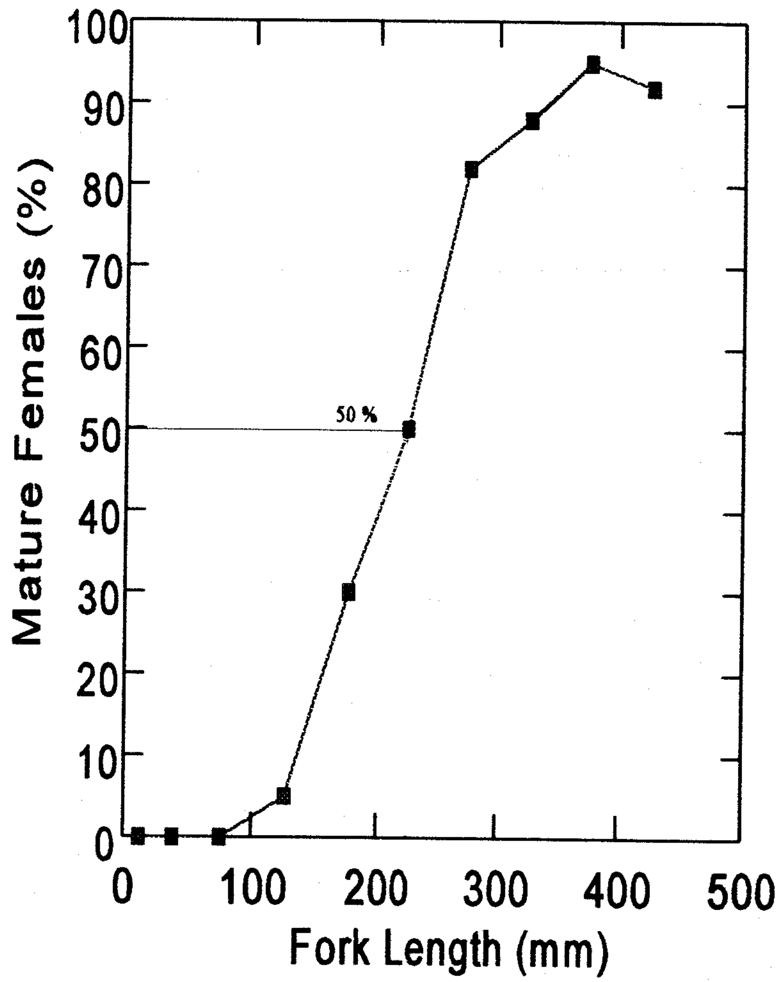


Fig 10: Length at maturity for female brook trout. Demarcation indicate 50% maturity level.

Table 9. Mean effort, yield (numbers and kg), yield (number/hectare and kg/hectare), effort (angler hours/hectare), CUE and the HWUE for each pond for the summer fishery (data taken from summer access point creels; 1992, 1993,1997 and 1998).

Pond	Effort (hrs)	Yield (#)	Yield (kg)	Yield (kg/h)	Effort (ah/ha)	CUE (no./hr)	HWUE (kg/hr)
Alleys	1045	321	87	0.21	2.6	0.45	0.12
Back-up	586	296	80	0.01	0.61	0.46	0.12
Big Bear Cave	2349	920	248	0.49	4.58	0.4	0.11
Big Wings	86	58	16	0.11	0.62	0.64	0.17
First	1129.5	169	46	0.01	2.02	0.35	0.01
Four Mile	504	176	47	0.11	1.21	0.35	0.01
Forked	97	118	32	0.33	0.17	1.22	0.33
Indian Bay	40	18	5	0.01	0.004	0.51	0.14
Indian Bay Big	4068	1179	319	0.29	3.71	0.33	0.01
Little Bear Cave	1071	363	98	0.49	5.35	0.37	0.1
Little Wings	-	-	-	-	-	-	-
Mocassin	514	72	19	0.04	1.02	0.15	0.004
Skippers	260	140	38	0.33	2.24	0.75	0.2
Southern	87	2	0.54	0..001	0.24	0.02	0.006
Third	204	51	14	0.05	0.75	0.46	0.12
All Ponds Combined	12041	3883	1050	0.19	2.16	0.32	0.1

Table 10. Mean effort, yield (numbers and kg), yield (number/hectare and kg/hectare), effort (angler hours/ hectare), CUE and the HwUE for each pond for the winter fishery (data taken from roving creels; 1994-1998).

Pond	Effort (hrs)	Yield (#)	Yield (kg)	Yield (kg/h)	Effort (ah/hec)	CUE (no./hr)	HWUE (kg/hr)
Alleys	321.6	262	66	0.16	0.78	0.72	0.18
Back-up	391	428	107	0.11	0.41	1.05	0.25
Big Bear Cave	311.6	285	71	0.14	0.61	0.92	0.23
Big Wings	102.3	124	31	0.03	0.09	1.17	0.29
First	134.6	133	33	0.06	0.24	0.86	0.21
Four Mile	272.8	311	78	0.19	0.65	1.14	0.29
Forked	263	376	94	0.17	0.46	1.81	0.45
Indian Bay	127	120	30	0.03	0.13	1.08	0.27
Indian Bay Big	468.3	794	117	0.1	0.73	0.59	0.15
Little Bear Cave	109	17	4	0.02	0.55	0.16	0.04
Little Wings	392	405	101	0.73	2.84	1.03	0.25
Mocassin	115	42	11	0.02	0.23	0.36	0.1
Skippers	354.4	311	78	0.67	3.05	0.89	0.22
Southern	568.4	312	78	0.21	1.56	0.65	0.16
Third	238	309	77	0.28	0.88	1.28	0.32
All Ponds Combined	4169	4229	976	0.12	0.51	1.01	0.23

Table 11. Mean effort, yield (numbers and kg), yield per hectare (number/hectare and kg/hectare), effort (angler hours/ hectare), CUE and the HwUE for each pond for combined winter and summer fishery.

Pond	Effort (hrs)	Yield (#)	Yield (kg)	Yield (kg/h)	Effort (ah/hec)	CUE (no./hr)	HWUE (kg/hr)
Alleys	1367	583	154	0.37	3.38	0.43	0.11
Back-up	977	724	187	0.12	1.02	0.74	0.19
Big Bear Cave	2661	1205	319	0.63	5.19	0.45	0.12
Big Wings	188	182	47	0.14	0.71	0.97	0.25
First	1265	302	79	0.07	2.26	0.24	0.07
Four Mile	777	487	125	0.3	1.86	0.63	0.16
Forked	360	494	126	0.49	0.63	1.37	0.35
Indian Bay	167	138	35	0.035	0.13	0.82	0.21
Indian Bay Big	4536	1973	436	0.39	4.44	0.29	0.1
Little Bear Cave	1179	380	102	0.51	5.95	0.32	0.09
Little Wings	392	405	101	0.73	2.84	1.03	0.25
Mocassin	629	114	30	0.06	1.25	0.18	0.05
Skippers	614	451	116	1	5.29	0.73	0.19
Southern	655	314	79	0.21	1.8	0.48	0.12
Third	442	360	91	0.33	1.63	0.81	0.2

Table 12. Mean annual effort, yield (numbers and kg), yield (number/hectare and kg/hectare), effort (angler hours/ hectare), CUE ,HwUE and release rates .

Fishery	Effort (hrs)	Yield (#)	Yield (kg)	Yield (kg/h)	Effort (ah/hec)	CUE (no./hr)	HWUE (kg/hr)	Release Rate (%)
Winter	4169	4229	967	0.12	0.51	1.01	0.23	14.4
Summer	12401	3883	1050	0.19	2.16	0.32	0.1	42.3
Annual	16570	8112	2017	0.31	2.67	-	-	

Table 13. Life history, fisheries and stock recruitment input parameters for Indian Bay Brook Trout exploitation model

Parameter	Value
Growth (Von Bertalanffy):	Linf = 40.6 cm K = 0.37
Weight-length (gm-cm):	$W = 0.0092 L^{3.05}$
Length at Maturation:	L50% = 22.5 cm L05% = 15.0 cm L95% = 30.0 cm
Length at Vulnerability (to angling):	L50% = 20 cm L05% = 15 cm L95% = 25 cm
Relative fecundity:	2540 eggs/kg
Max early survival (egg to age 1)	0.0068
Natural mortality (instantaneous, age >= 1)	M = 0.45/yr
Stock-recruitment (Shepherd function)	Recruits at age 1= Max Rec rate * Spawn Biomass/ (1 + (Spawning Biomass/Bo)^Beta)
Beta (shape)	1
Bo (related to carrying capacity)	1.5 kg/ha
Maximum recruitment rate (Max early survival x relative fecundity)	17.3
Catchability:	q = 0.07 hectare/hr