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Conservation Requirements for Atlantic salmon (*Salmo salar* L.) in Labrador rivers

Besoins de conservation du saumon atlantique (*Salmo salar* L.) dans les cours d'eau du Labrador

by

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ABSTRACT

This paper provides interim methods and results for setting conservation requirements for Atlantic salmon (*Salmo salar* L.) in Labrador. The current standard conservation requirement of 240 eggs per 100 m^2 of parr-rearing habitat used for some Eastern Canadian rivers was deemed questionable for Labrador because Labrador rivers are on the northern edge of the range of Atlantic salmon and have a much colder climate. As a result of the colder climate, Labrador salmon generally spend longer in freshwater than do salmon populations to the south. Also, many Labrador rivers have abundant anadromous charr (*Salvelinus alpinus* L.) and trout (*Salvelinus fontinalis* Mitchill) which are not present in rivers to the south and may compete with salmon in freshwater for space and food. Because Labrador salmon are exploited in FSC (fisheries by aboriginal people for food, social and ceremonial purposes) fisheries in addition to angling, it requires the development of an interim value until such time that more definitive reference points can be developed. The preferred approach to defining biological reference points is through the analysis of stock and recruit relationships (SR). The collection of a sufficient SR time series requires a number of years of measured spawners and adult returns which do not exist for any Labrador river. We examined three previously published methods for deriving conservation limits and describe three alternate approaches for Labrador. The first of these alternate approaches is based on a quasi-stock and recruit method and uses fishery generated SR data. The second considers measured smolt production from Sand Hill River adjusted to variable freshwater survival rates. The third converts angling catch rates and river returns from a counting fence to construct SR data from a limit of 50% of the equilibrium population. Results from the three methods show 161 (95^{th} CL 110 to 309) eggs per 100 m^2 for the quasi-SR approach and 152 (95^{th} CL 80 to 370) eggs per 100 m^2 based on the Sand Hill smolt production data and 187 (95^{th} CL 153 to 201) from the SR analysis of Sand Hill River fence and angling data. Based on the data and analysis and until more information can be collected at higher escapements, it is recommended that a management target of 240 eggs per 100 m^2 and a conservation limit of 190 eggs per 100 m^2 be adopted.

RÉSUMÉ

Le document présente des méthodes provisoires et des résultats permettant d'établir les besoins de conservation du saumon atlantique (*Salmo salar* L.) au Labrador. La norme actuelle des besoins de conservation de 240 œufs par 100 m^2 d'habitat de croissance des tacons, utilisée pour certains cours d'eau de l'Est du Canada, a été mise en question pour le Labrador, parce que les rivières s'y trouvent à l'extrémité nord de l'aire de répartition du saumon atlantique et que le climat y est beaucoup plus froid. Par conséquent, le saumon du Labrador passe en général plus de temps en eau douce que les populations de saumon du sud. De plus, dans beaucoup de cours d'eau du Labrador, les ombles (*Salvelinus alpinus* L.) et les truites (*Salvelinus fontinalis* Mitchill) anadromes sont abondantes, alors qu'elles sont absentes dans le sud. Elles pourraient concurrencer le saumon pour l'espace et la nourriture en eau douce. Puisque les saumons du labrador sont exploités dans le cadre de pêches pratiquées par les Autochtones à des fins alimentaires, sociales et rituelles en plus de la pêche sportive, il faut définir une valeur provisoire d'ici à ce que des points de référence définitifs puissent être établis. La méthode privilégiée pour déterminer les points de référence biologiques est l'analyse des relations stock-recrues (SR). L'obtention d'un nombre suffisant de séries chronologiques SR nécessite la mesure des retours de géniteurs et d'adultes pendant un certain nombre d'années, ce qui n'existe pas pour les cours d'eau du Labrador. Nous avons examiné trois méthodes, publiées antérieurement, pour le calcul des limites de conservation et décrivons trois méthodes différentes pour le Labrador. La première est basée sur une analyse qui ressemble de près à l'analyse SR et qui fait appel à des données de SR recueillies au cours de la pêche. La deuxième prend comme point de départ la production mesurée des saumoneaux de la rivière Sand Hill, rajustée selon les taux de survie en eau douce variables. La troisième convertit les taux de prises sportives et les retours à une barrière de dénombrement de manière à obtenir des données de SR à partir d'une limite de 50 % de la population d'équilibre. Les résultats des trois méthodes donnent 161 (limite de confiance de 0,95, allant de 110 à 309) œufs par 100 m^2 pour l'analyse semblable à l'analyse SR, 152 (LC de 0,95, allant de 80 à 370) œufs par 100 m^2 pour les données de production de saumoneaux de la rivière Sand Hill et 197 (LC de 0,95, allant de 153 à 201) œufs par 100 m^2 à partir de l'analyse SR basée sur les données de la pêche sportive et de la barrière de dénombrement de Sand Hill. D'après les données et l'analyse et d'ici à ce qu'on puisse recueillir plus d'information sur l'échappée à des points situés plus en amont, il est recommandé d'adopter une cible de gestion de la ponte de 240 œufs par 100 m^2 et une limite de conservation de 190 œufs par 100 m^2.

INTRODUCTION

The conservation and rational management of all fish stocks including Atlantic salmon (*Salmo salar*) is bound in principles set forth in the United Nations Law of the Sea (United Nations 1982) and more specifically for salmon by the North Atlantic Salmon Conservation Organization (NASCO) of which Canada is a member. Both organizations hold conservation as paramount such that conservation concerns must be addressed before harvesting can take place. In Eastern Canada, the Canadian Atlantic Fisheries Scientific Advisory Committee (CAFSAC 1991a&b) adopted the following definition of conservation based on the 1980 United Nations Environment Program:

> "*That aspect of renewable resource management which ensures that utilization is sustainable and which safeguards ecological processes and genetic diversity for the maintenance of the resource concerned. Conservation ensures that the fullest sustainable advantage is derived from the resource base and that facilities are so located and conducted that the resource base is maintained*".

In addition to the formal definition, CAFSAC also recognized the need for an operational translation of conservation based on the concept of a '*stock*' which refers to all of the fish spawning in a particular lake or stream. Lately, in addition to the above definitions, NASCO has also adopted the *Precautionary Principle* which states that uncertainties in parameter values used to operationally define conservation should be taken into account by setting limits higher than biologically derived values.

Biological reference points (BRPs) that identify safe biological limits for exploiting fish stocks can be determined in a number of ways (Potter 2001; Crozier et al. 2003). For Atlantic salmon on both sides of the Atlantic, the BRP chosen to represent the conservation limit (CL) is the level of stock that will achieve long-term maximum sustainable yield (MSY) to fisheries, also termed S_{msy} or S_{opt} (Chaput 1997; ICES 1993). Operationally for Atlantic salmon in eastern Canada, the CL is expressed as a conservation requirement based on the potential productivity of rivers using the egg deposition rate of 240 eggs per 100 m^2 of fluvial rearing habitat and, in addition for insular Newfoundland, 368 eggs per hectare of lacustrine habitat (or 105 eggs per hectare in northern rivers) (O'Connell and Dempson 1995). The value of 240 eggs was determined from a stock and recruit graph from the early work by (Elson 1957, 1975) and is the egg deposition that maximizes smolt production (Chaput 1997). In Europe, the CL is determined from overcompensation type stock and recruit (SR) relationships in terms of maximizing adults which are sometimes expressed as eggs. For Eastern Canadian rivers, specific egg depositions are then determined for each river depending on the amount of rearing area in fluvial and lake habitat. Finally, with parameter values defining the stock characteristics of the river, the egg requirement is then converted to numbers of salmon including consideration of the stock structure in terms of its one-sea winter (1SW or grilse) and multi-sea winter (MSW) components. Examples of this approach are provided in (O'Connell and Dempson 1995) and (O'Connell et al. 1997). We note that alternate methods have also been proposed by (Chaput et al. 1998) which provide lower levels than the 240 standard. In Québec, based on SR data from six rivers, (Caron et al. 1999) calculated values of 145 to 190 eggs per 100 m^2 (mean of 182) to maximize adults.

Conservation requirements for individual Labrador rivers are as yet undefined partly because of a lack of Labrador-specific egg deposition rates as well as habitat information to base them on. Additionally, DFO (2002) noted that the use of 240 eggs per 100 m^2 of fluvial habitat and 368 or 105 eggs per hectare of pond habitat assumed for other Eastern Canadian rivers may not be appropriate for Labrador due to the presence of more year classes in freshwater arising from the harsher climate. As there have been very few stock inventory projects on Labrador rivers and those that have been undertaken have been of short duration, there consequently is insufficient SR data for analysis. Second, as Labrador salmon spend longer in freshwater than is generally the case elsewhere in North American rivers, a sufficient time series of SR data will require 25 or more years to develop. And even then, it may be difficult to extrapolate from data collected on one river to the many other rivers of Labrador. (O'Connell et al. 1997) derived conservation requirements separately for Salmon Fishing Areas (SFAs) of Canada including Labrador that have been used by the International Council for the Exploration of the Sea to provide advice on fisheries harvesting large MSW salmon at Greenland and in North America. Because of the presence in Labrador of extensive net and angling fisheries, there is a concomitant risk of recruitment overfishing and hence efforts are needed to derive acceptable reference or conservation levels for Labrador rivers (Walters and Korman 2001). The purpose of this paper is to provide and document alternate determinations of a biological reference point to be used to set conservation limits for use in Labrador until such a time as sufficient data is collected to establish a stock and recruit relationship(s).

THE FISHERIES

Currently, there are two fisheries harvesting salmon in Labrador, viz. angling in freshwater and aboriginal net fisheries in the sea. The harvest regimes in both have been highly variable over the years. In 2005, the recreational salmon fishery in freshwater for all Labrador rivers opened on 15 June and closed 15 September. In SFA 1 and some SFA 2 rivers (Fig. 1), anglers can retain four salmon for the season, one of which can be large (fish greater then or equal to 63 cm); while other scheduled salmon rivers in SFA 2 have a season retention limit of two small salmon (fish less then 63 cm) and no large salmon can be retained. Retention of large salmon is not permitted in SFA 14B. Differential treatment of large from small salmon is based on declining numbers of large salmon and their considerable contribution to egg deposition based on their larger size and higher percentage of female salmon than small.

In the sea, commercial fishing in Labrador ceased in SFA 14B in 1997 and in SFAs 1 and 2 in 1998 (Fig. 1). Labrador origin salmon were also caught along the northeast coast of Newfoundland in a commercial salmon fishery that was closed in 1992. Labrador salmon have also been caught at Greenland where commercial salmon fishing was suspended in 2002. Greenlanders continued a subsistence harvest in 2002-05 that possibly harvests Labrador origin salmon but in relatively low numbers compared to the past. Aboriginal subsistence fisheries for salmon, Arctic charr (*Salvelinus alpinus* L.) and sea trout (*Salvelinus fontinalis* Mitchill) take place in Labrador under communal licence. There are three groups with subsistence fisheries, viz. Nunatsiavut Government (formerly the Labrador Inuit Association), Labrador Metis Nation, and the Innu Nation. There is also an All Resident Subsistence Fishery for trout and charr with a permitted retention of up to four salmon as a by-catch. From 2000 to 2004, salmon landings in the subsistence fisheries in Labrador have varied between 16 and 32 t (DFO 2005).

DEFINITIONS

In this paper, we use the following terms based on (Chaput 1997), (Prévost and Chaput 2001), and (Crozier et al. 2003a&b):

Biological Reference Points (BRPs): are "signposts" or benchmarks which can be calculated from life history characteristics and describe a population's state in either biomass or numbers. Generally for salmon, numbers of fish or eggs are used.

Conservation limits (CLs): are BRPs that set strict boundaries intended to constrain losses within safe biological limits sometimes referred to as thresholds below which no human-induced mortality should take place. In Eastern Canada, the standard value is 240 eggs per unit (one unit = 100 m^2) of fluvial parr rearing habitat with the addition of 368 in Newfoundland rivers (105 in northern Newfoundland and Labrador rivers) eggs per hectare of pond habitat. The standard is used as a default when no other more relevant values are available. Conservation limits are generally determined from a SR graph at the point of maximum production and are synonymous with terms such as MSY, $S_{lim,}$ B_{lim} and S_{opt}.

Conservation requirements (CRs): the egg deposition for a river required to achieve a level that will protect the stock from future declines and extirpation. It is derived as the product of the CL and the number of units of fluvial and lacustrine habitat in a river or tributary.

Management targets (MTs): levels to aim for or a desired state intended to meet management objectives which may include setting levels above the biologically recommended CL for social and other reasons including those related to the Precautionary Principle.

METHODS

For animal populations, it is generally assumed that there is a relationship between the abundance of the parental stock (S) and the number of recruits (R) it produces. There are several of these 'stock and recruit' (SR) models that are generally applicable to both marine and freshwater fish (Ricker 1975; Hilborn and Walters 1992; Myers at al. 1995) depending on assumptions of density dependence or independence from the number of juvenile fish at some early point in their life cycle. Specifically for salmonids, the early work of (Elson 1957, 1975) followed by (Chadwick 1982), (Buck and Hay 1984), (Chadwick and Randall 1986) (Caron et al. 1999) and more recently Crozier et al. (2003a) as examples, clearly showed that SR relationships exist and can ultimately be used to define CLs for Atlantic salmon (CAFSAC 1991a&b; Chaput 1997). In this context, CLs have traditionally been set using stock and recruit data from individual rivers and analyzed with either Ricker-type and/or Beverton-Holt-type SR models (Ricker 1975). When a clear pattern emerges from the SR graph, reference levels for the stock and CLs can then be interpreted. Frequently, SR data is non-existent and/or that which does exist shows too much variation in recruitment based on the spawning stock (Walters and Korman 2001) making determination of CRs problematic. Also due to non-stationarity, CLs can change substantially over time and/or vary from river to river, in particular, when long distances separate the rivers in question (Crozier et al. 2003a&b). We review several derivations of CRs and BRPs then comment on their utility for use in Labrador.

Irrespective of the technique, all methods will require estimates of parr rearing area in individual Labrador rivers and some will require estimates of total rearing habitat in all rivers to convert total eggs to eggs per unit. (Reddin et al. 2004) show rearing area and drainage area for many of the known salmon rivers in Labrador. Sand Hill River for instance has 1,509 km^2 accessible out of a drainage area of 1,603 km^2. The parr rearing area is 53,154 units for the accessible portion of the watershed. In total, Labrador has an estimated 1,037,520 units of parr rearing area. This value should be regarded as a minimum as not all rivers in Labrador and especially Lake Melville are included due to a lack of survey information.

FRESHWATER PRODUCTION (SYMONS 1979)

(Symons 1979) concluded that egg deposition in salmon rivers would vary depending on the age of smolt produced. This occurs, hypothesized Symons, because carrying capacity is lower in harsher northern climates resulting in a higher proportion of older smolts being produced thus lowering the required egg deposition from what might be determined for southern rivers. Labrador salmon are known for older age smolts. For example, Sand Hill River smolts and returning adults are dominated by 4 and 5 year old river age fish with some river age six (Reddin et al. 1996). Big Brook and English River further north in Labrador can have as much as one quarter of the returning adults produced from river age six smolts (Reddin et al. 2001a&b). If freshwater survival is similar to southern rivers and carrying capacity is density dependent then the result of the presence of older smolts in Labrador is lower production and therefore lower required egg deposition to maintain maximum production. (Symons 1979) provides egg deposition requirements for 4+ smolts that could possibly be used in the context of this paper.

PORTION (30%) OF HIGH RECRUITMENT (O'CONNELL ET AL. 1997)

(O'Connell et al. 1997) derived CRs for Atlantic salmon in eastern Canada to be used to provide advice to fisheries managers on the commercial salmon fishery at west Greenland that harvests mainly 2SW salmon (ICES 2005). A variety of methods were used depending on region. For most of Eastern Canada, (O'Connell et al. 1997) used the then standard CL of 240 eggs per unit of rearing habitat (Elson 1975; Chaput 1997). For Newfoundland, where it was known that salmon rear as parr in lake habitat, a further 368 eggs per hectare of lake surface was added (105 per hectare in northern areas). For Labrador, due to a lack of survey information and sufficient resolution in the 1:250000 maps available then, an alternate method based on commercial catch statistics was used. This alternate method consisted of estimating returns to Labrador based on commercial catches raised to total returns by applying exploitation rates developed from tagging experiments at Sand Hill River with a further adjustment to remove non-Labrador salmon (Pratt et al. 1974). The total returns included estimates from salmon caught at Greenland and along the northeast coast of Newfoundland (*for more details on the methods see* Rago et al. (1993 a&b); ICES (2005)). (O'Connell et al. 1997) then derived required spawners by assuming that one spawner would on average generate three recruits. The period of time used was 1974-78 which appeared to be a time of high production for Labrador salmon.

EASTERN CANADA STANDARD (ELSON 1975; CHAPUT 1997)

As outlined in the Introduction there currently is a standard egg deposition rate for Eastern Canadian rivers. The standard rate is 240 eggs per unit of rearing habitat and is applied to a measure of the total rearing units derived from survey data for each river (Elson 1975; Chaput 1997). When combined with estimates of adult spawners and biological characteristics, i.e. fecundity and sex ratios; the annual egg deposition can be estimated and then compared to the standard. (Reddin et al. 2004) indicated that there are 1,037,520 m^2 of rearing habitat in Labrador; although not all rivers have been surveyed and some surveys are weak due to the use of 1:250000 maps that were the only ones available at the time (Anderson 1985). The potential rearing of salmon parr in lakes and ponds (lacustrine habitat) is unknown for Labrador and needs resolving. (Reddin et al. 2001) reported that very few salmon parr were caught in fyke nets fishing in English River Pond in northern Labrador. However, (Hammar and Filipsson 1985) report the capture of salmon parr and smolts in various ponds of Sand Hill River in southern Labrador.

QUASI SR RELATIONSHIP FROM COMMERCIAL LANDINGS

Conservation limits have traditionally been set using stock and recruit data from individual rivers and analyzed with either Ricker-type and/or Beverton-Holt-type models (Ricker 1975). However, frequently SR data is non-existent and/or that which does exist shows too much variation in recruitment based on the spawning stock for a clear pattern to emerge (Walters and Korman 2001). Such is the case with Labrador. First, there have been very few stock inventory projects on Labrador rivers and consequently no SR data exists for analysis. Second, as Labrador salmon spend longer in freshwater due to the harsher climate than is generally the case elsewhere in eastern North America, adequate SR data will take years to compile even if we were to begin now. Clearly, some interim value derived else wise is required.

(Bradford et al. 2000; Barrowman and Myers 2000; Gibson and Myers 2004) described a new technique for estimating BRPs from noisy SR data labelled the 'hockey stick' approach. The hockey stick method is used in a quasi-stock and recruit analysis when more precise data for use by traditional methods are unavailable. This follows the approach used for European salmon by ICES (2005) described by (Potter and Nicholson 2001).

In order to provide catch advice to NASCO, the ICES North Atlantic Salmon Working Group developed a method, termed run reconstruction, of estimating the total numbers of North American 1SW and 2SW salmon prior to the fisheries that harvest them (Rago et al. 1993a). The North American pre-fishery abundance estimates (PFAs) were determined from sets of return and spawner numbers for six geographic regions covering the whole of North America (Rago et al. 1993b; Friedland et al. 2003) and are used to forecast the following years PFA and subsequently provide catch advice (Reddin et al. 1993; Chaput et al. 2005). For Labrador, as the data was based on commercial catch statistics raised to total numbers by exploitation rates based on tagging studies at Sand Hill River, the time series ended in 1998 when the commercial fishery closed (Reddin 1999; ICES, 2004). In addition, because the Labrador data was derived from commercial catches and includes estimates for the number of Labrador salmon caught at Greenland and

Newfoundland, the numbers estimate recruits of Labrador small and large salmon, 1969-98 (Table 1).

SR RELATIONSHIP FROM ANGLING CATCHES

Recreational catch and effort data is available for Sand Hill River from 1964 to 2005 (Table 2). Effort data was not available for three years 1975, 1976 and 1981. Smolt and adult counts from a fence operated by DFO in 1970-73 (Pratt et al. 1974), adult counts in 1994-96 (Reddin et al. 1996) and 2002-05 (D. Reddin pers. comm.) provide an opportunity to derive a population time series calibrated by population counts (Tables 3 and 4). Time series of population estimates were derived from the formula:

$$C = NqE \qquad (1)$$

where, C = Recreational catch
N = Population
q = Catchability coefficient
E = Effort in Rod Days

For the years when the fence was operated N is known and q was estimated for the recreational fishery relative to effort as:

$$q_i = (C_i / E_i) / N_i \qquad (2)$$

The error distribution of this relationship is known to be log normal (Myers et al. 1995) and therefore q was estimated on the log scale by minimizing the error sums of square (SSE) between $N_{observed}$ and $N_{predicted}$ of the log transformed data using equation 2.

Lognormal error of q was estimated by the formula:

$$Sigma = \delta = \sqrt{SSE^2 / n} \qquad (3)$$

where n = sample size.

The resultant mean value of q_{mean} was corrected to the arithmetic scale by the formulae:

$$q_{Corrected} = Ln(q) + (SSE^2 / 2) \qquad (4)$$

Confidence limits for $q_{corrected}$ were determined from the lognormal error distribution of the $q_{corrected}$ at p=0.025 and p=0.975.

In years when a count was not available, N or the population of salmon was estimated at the midpoint estimate and the 95% confidence range of $q_{corrected}$ by the formulae:

$$N_i = (C_i / E_i) * 1 / q_{Corrected} \qquad (5)$$

Annual egg depositions were derived as:

$$Eggdeposition = N * Eggs/salmon \quad (6)$$

The number of Eggs per Salmon was derived as:

$$Eggs/salmon = \sum_{Size}(proportion_{Female} * weight_{kg} * eggs_{/kg/Female} * proportion_{Size}) \quad (7)$$

The proportion by size were defined as small salmon (<63 cm) and large salmon (≥63 cm). Proportions for size, weight and eggs per female salmon were estimated by (Reddin et al. 1996) and resulted in 2,992 eggs per salmon.

The annual proportionate contribution that an egg deposition makes to a smolt cohort was from ICES (2005):

Egg to smolt contribution proportions				
Year i-4 to i-7	0.077	0.542	0.341	0.040

These data and calculations were used to derive a stock and recruitment relationship for eggs to smolts for the Sand Hill River for the years when a smolt fence was operated.

Because no overcompensation, i.e. declining numbers of smolts at higher egg depositions, was observed for this data and is not reported for any other Atlantic salmon data (Myers et al. 1995) these data were used to estimate a compensatory Beverton and Holt type stock and recruit relationship. Beverton and Holt report two formulations for this relationship. One is used to derive an initial proportion of smolts per egg at the origin (slope at the origin) and the asymptotic maximum smolt production and the other is used to derive the half saturation point. The first formula used was to derive the slope and maximum:

$$\text{Smolts} = \alpha * \text{Eggs}/(1 + \alpha * \text{eggs}/\text{R}_{\text{max}}) \quad (8)$$

where α = slope at the origin and R max is the asymptotic maximum smolt production.

The second Beverton and Holt stock and recruit formula was:

$$\text{Smolts} = \alpha * \text{Eggs}/(1 + \text{Eggs}/\text{K}) \quad (9)$$

where K = the half saturation point of smolt production for the range of egg depositions.

Parameter estimates were obtained by minimizing an objective function (OBV) derived as the sum of the negative log likelihoods for the observed and predicted values (Myers et al. 1995) by the formula:

$$\lambda(Obs|\alpha, R, \sigma) = -\frac{n}{2} * Ln\left[\frac{2\pi}{n}\sum\left(Ln\frac{Obs}{Pred}\right)^2\right] - \sum LnObs - \frac{n}{2} \quad (10)$$

The numbers of spawners per recruit were calculated as eggs per recruit (EPR) by the following formulae:

$$EPR = Eggs / Salmon * Survival_{\substack{Smolt \\ to \\ adult}} \qquad (11)$$

Marine survivals were those for the smolt estimates of 1970-73 (Reddin et al. 1996) and were for both river return and local fishery return. No account for iteroparity was included.

The reciprocal of the Egg Per Recruit (EPR) was the slope of the replacement line. When calculated over a range of egg depositions the point at which the replacement line intersects with the stock and recruitment line was termed the equilibrium point. This point was estimated using the method of (Gibson and Myers 2003) for Beverton and Holt equations. The formula was:

$$Equilibrium = \alpha * EPR - 1) * R_{\max} / \alpha \qquad (12)$$

ADJUSTED FRESHWATER PRODUCTION

An alternate approach to derive interim conservation spawning requirements for Labrador salmon rivers modifies the conventional method used to determine spawning requirements in Newfoundland rivers by (O'Connell and Dempson 1995). For most insular Newfoundland systems, the latter approach assumed the production of three smolts per unit of fluvial habitat and seven smolts per hectare of lacustrine habitat to derive a BRP for total smolt production. However, for rivers on the northern peninsula, a value of two smolts per hectare of lacustrine habitat was recommended. With egg-to-smolt survival of 0.0125 for fluvial habitat and 0.019 for lacustrine habitat, potential smolt numbers were then converted into required numbers of eggs. A somewhat similar approach, but working from known measured smolt production, could be applied to data from Sand Hill River, Labrador, rather than assume a constant smolt production of three smolts per unit of fluvial habitat.

Data were available on the production of smolts from Sand Hill for the years 1970-73 (Anderson 1985). Smolt numbers, corrected from (Anderson 1985), ranged from 37,109 to 52,607 (average = 47,083). Average smolt production and number of units of fluvial habitat were as follows:

Sand Hill River habitat units	=	53,154
Average (rounded) number of smolt	=	47,100

Based on these data, the number of smolt per unit would be 0.886 (using the mean number of smolts). However, estimates of smolt production measured in those years were derived from salmon spawners that escaped Labrador coastal and distant fisheries. Hence, it is possible that smolt production could have been somewhat higher if escapements to Sand Hill River had been greater.

The closest river to Sand Hill with a long time series of smolt production data is Western Arm Brook (SFA 14A), located approximately 250 km to the south, on the west coast of the northern peninsula. However, only 3 years of data from Western Arm Brook

(1971-1973) overlap with the period of smolt monitoring at Sand Hill, and two of these years have among the lowest numbers of smolts produced. Also in the intervening years, moratoria have been placed on commercial fishing in both Newfoundland beginning in 1992 and in Labrador beginning in 1997. Consequently, to determine an appropriate change in productivity between pre-moratorium and moratorium years, the 10-year period 1971-80 was compared with the smolts produced from 1996 to 2004 at Western Arm Brook. This was done by bootstrapping, with replacement, actual numbers of smolts within each of the two time intervals, calculating the mean number of smolts for each period and then determining the percentage change. This was repeated 2000 times and the median increase was found to be 36.6%. Hence, should a similar increase have occurred at Sand Hill River in the absence of some directed ocean fisheries, then smolt production could also be higher by about 40% (rounded) or so, on average. Thus, a value of 66,000 smolt was selected for further analysis. This represents an approximate 40% increase applied to the average number of smolts observed and yielded a hypothetical point-estimate production of 1.24 smolts per habitat unit. This value could then be divided by freshwater (egg-to-smolt) survival to provide an estimate of the number of eggs required per unit of fluvial habitat.

For Sand Hill River, egg-to-smolt survival was assumed to be similar to that observed at Western Arm Brook. Based on data derived from 29 year classes, egg-to-smolt survival was 1.39%, with a coefficient of variation equal to 58%. However, as egg deposition increases, egg-to-smolt survival at Western Arm Brook declined; a situation similar to that observed in other Newfoundland rivers (Klemetsen et al. 2003). Consequently, egg-to-smolt survival for the past decade was used, coinciding with the period of increased egg deposition and smolt production. This value averaged 0.814% (CV = 62%).

Thus for Sand Hill River, freshwater survival was allowed to vary from 0.33 to 1.30%. Similarly, the number of smolts produced were also allowed to vary. Based on the variability observed at Western Arm Brook during the past decade, the coefficient of variation about either the annual numbers of smolt produced or numbers produced by year-class was about 30%. Consequently, hypothetical smolt production at Sand Hill River was allowed to vary from 46,000 to 86,000 smolts. The approach to derive potential reference levels based on this hypothetical smolt production for Labrador salmon was as follows:

Number of smolts varied from 46,000 to 86,000; and,
Freshwater (egg-to-smolt) survival varied from 0.33% to 1.30%.

Smolt numbers were divided into the number of fluvial units for Sand Hill River (53,154) with the corresponding number of smolt per unit divided by the egg-to-smolt survival values. The calculation was repeated with 2,000 realizations using a uniform distribution for survival and smolt numbers.

RESULTS

FRESHWATER PRODUCTION (SYMONS 1979)

(Symons 1979) provided egg deposition requirements for 4+ smolts of 80 eggs per 100 m^2. If adjusted for Elson's factors, Symon's value could be used as a CL for Labrador. This was referred to as virtual egg deposition by (Symons 1979) as distinct from the potential egg deposition of (Elson 1975). Elson's potential egg deposition which included a buffer for removals of adult salmon prior to spawning from poaching, disease and predation was used by CAFSAC (1991 a&b). Adjustment to the potential egg deposition gives a value of approximately 100 eggs per 100 m^2 for rivers producing 4+ smolts. This value appears very low in comparison to the 240 eggs per unit derived by CAFSAC (1991 a&b) which may be due to the unknown status of the rivers used in the Symons analysis. (Symons 1979) used data from various rivers then available which were at differing egg deposition levels and not necessarily at maximum production. As we have stated, CLs should be based on some maximum sustainable level to best protect stocks from over-harvesting and so the adjusted Symon's value is rejected for this reason.

PORTION (30%) OF HIGH RECRUITMENT (O'CONNELL ET AL. 1997)

The mid-point of the derived spawning requirements for Labrador from the catch-based data is 59,400 small salmon (34,000-84,900) and 48,200 (35,570-60,840) large salmon (O'Connell et al. 1997). The value of 48,200 large salmon was reduced to 34,750 2SW salmon to provide catch advice for West Greenland and North America fisheries. To do so required converting the 34,750 salmon to 2SW equivalents at West Greenland by correcting for natural mortality and the proportion of 2SW salmon in Labrador. The total spawner requirement for Labrador including small and large salmon then would equal about 107,700 salmon. While this is suitable for use at Greenland, it does not provide conservation requirements that are useable at a stock level as it only provides a total for all of Labrador. Therefore, it is not possible to use it to determine CRs for Labrador rivers.

EASTERN CANADA STANDARD (ELSON 1975; CAFSAC 1991A&B; CHAPUT 1997)

(Elson 1975) followed by CAFSAC (1991 a&b) and later reviewed by (Chaput 1997) developed an Eastern Canadian standard of 240 eggs per 100 m^2 of parr rearing habitat based on a SR relationship from data on the Pollett River, NB collected in the 1950s and 1960s. CSAS (2003) reviewed it for use in Labrador and because of the complicating factors of harsher climate and older smolts compared to the Pollett River in New Brunswick, it was recommended that a value more relevant to the biology of Labrador salmon be found for use as a CL. Also, non-stationarity or shifts in parameter values could cause considerable difference between what might be currently valid and the Pollett River data which is over 30 years old. Thus, use of the Eastern Canadian standard of 240 eggs per unit of parr habitat is not recommended as a CL for Labrador salmon stocks.

QUASI SR RELATIONSHIP FROM COMMERCIAL LANDINGS

The data of recruits and spawners shows a range of lagged spawners from 41,837 to 143,938 and for recruits of 79,136-470,381 (Table 1). The quasi-stock and recruit plot shows an inflection point at 74,848 which would then be the recommended conservation limit (95^{th} CI 42,000-144,000) (Fig. 2). Comparison of spawners to the conservation limit at 74,848 indicates that the CL was exceeded in 16 out of 22 years (Fig. 3).

The conversion of 74,848 small and large salmon spawners to eggs per unit requires the conversion of fish to eggs and then expressed as units of rearing habitat. Biological characteristics are available for Sand Hill River (Reddin et al. 1996) and percent small in the returns to the river are available from seven rivers in Labrador (Reddin et al. 2005). Fecundity of Labrador salmon is 68.2 eggs per cm fork length for small and 67.5 eggs per cm fork length for large salmon. Average fork lengths at Sand Hill River were 56 cm for small and 76 cm for large (Reddin et al. 1996). Small salmon were approximately 50% female and large salmon were 80% female (Reddin et al. 1996). Because the CL is in adult salmon it must first be reduced to small and large salmon and then to eggs. This was done using the average of the proportion of small and large salmon in the returns to the counting fences in Labrador (CSAS 2005) of 0.85 small and 0.15 large:

CR_{adults} = 74,848 * 0.85 (or 0.15 for large) = 63,621 small salmon (or 11,227 large)

CR_{eggs} = (63,621*0.50*56*67.5) + (11,227*0.80*76*68.2)
= 120,243,690 + 46,553,429
= 166,797,119

The egg deposition required for conservation of 166,797,119 eggs was divided by the number of fluvial units for Labrador rivers from (Reddin et al. 2004) so that the conservation requirement could be expressed as egg deposition per 100 m^2. In total, there are 1,037,520 units (1 unit = 100 m^2) of accessible rearing area in Labrador; inclusive of six Lake Melville rivers. The resulting median number of eggs per unit required for conservation was 161, with corresponding 95% confidence bounds of 110-309.

SR RELATIONSHIP FROM ANGLING CATCHES

A Beverton Holt stock and recruitment relationship between smolts and cohort eggs was developed from the four years of count data (Tables 2-4 and Fig. 4) and angling catch and effort data from Sand Hill River (Table 2). The count of smolts from Sand Hill River ranged from 37,007 in 1972 to 55,000 in 1971.

Using the partial recruitment rates to smolts reported in this paper and in the cited literature, cohort eggs at the 2.5, 50 and 97.5 percentiles of population estimates of adult salmon estimates of egg depositions for each smolt year from 1970 to 2005 were derived. Estimates of annual escapements based on the catch and effort data were constrained within the 99% CI (0.000213 to 0.000932) for $q_{corrected}$ for 1964-73, 1975, 1991, and 1994-2005. Only these values were carried forward for subsequent analysis (Table 4).

The range in egg depositions was 1.313* 10^6 in 1967 to 17.877* 10^6 in 1975 and has been about 8-15 million eggs in the past 5 yrs (Fig. 5). Cohort eggs that contributed to smolts in 1970-73 ranged from 2.1×10^6 for the 1973 smolt run to 3.167×10^6 eggs for the 1970 smolt run. Estimated egg to smolt survival ranged from 1.47 to 2.1% and the number of smolts produced per spawning salmon ranged from 48 to 68 smolts per spawning fish. Both of these are higher than many reported values but are not unreasonable.

Based on these estimates of egg depositions and the smolt counts, asymptotic[a] and half saturation[b] models, see equations (8) and (9), were estimated by minimising the negative log-likelihood ratio (Fig. 4). R_{max} was estimated at 105,895 smolts and the half saturation point (K) was 3,161,784 eggs.

A replacement line, the reciprocal of eggs per fish (1/2,992) times the marine survival rate of 0.073 to the river and 0.114 to the area (pre-fishery) for the anchor years 1970-74 was estimated for both the river population and the local pre-fishery population. The spawner per recruit in eggs was 218 for the river and 341 for the local pre-fishery population. Equilibriums, the place where recruit eggs equals that required for spawners to produce them, were estimated using the method of (Gibson and Myers 2003) for Beverton and Holt SRs and found to be 19,560,755 eggs or 374 egg per unit for the river and 32,570,068 eggs or 619 egg per unit for the pre-fishery population.

Based on the methods of (Mace 1994) and (Myers et al. 1994), the 50% of R_{max}, a threshold reference point for over fishing (Myers et al. 1994) terminology) of 3,210,832 eggs or 60 (29 to 125; based on 95% CI for $q_{corrected}$) eggs per 100 m^2 rearing unit based on an estimate of 53,154 x 100 m^2 was derived for the Sand Hill River. Assuming an un-fished population (virgin biomass) equal to the pre-fishery replacement line and 20% of the virgin (BHv) biomass method of (Myers et al. 1994), the number was 6,577,814 eggs or 124 (110-129; based on 95% CI for $q_{corrected}$) eggs per rearing unit. A third reference point, 187 eggs per unit (153-201; based on 95% CI for $q_{corrected}$) at 50% of the equilibrium point of the fished population was calculated as an alternative.

In relation to the above reference points, cohort eggs and the lower reference point cohort eggs was attained in 21 of 24 (87.5%) years where estimates were available, 19 of 24 (79.2%) years at the higher 20% of BHv rate and 10 of 24 (41.7%) years were higher than 50% of the equilibrium point (Fig. 5).

Examining the data for the Sand Hill River, one notes that the calibration points are less than or approximate to K, the asymptote for smolt production is much higher than observed and recent cohort egg depositions are frequently double that of the earlier period when the counts were made (Fig. 6). However, it should also be noted that the model fit of the population estimates compared to the actual counts is reasonable given the short time series (Fig. 7). This means that there is sound argument for increased egg depositions that could result in increased smolt production. Increased smolt production could lead to more age class overlap in spawners which is considered a genetic benefit. It would be of value to observe the smolt counts from the recent increased escapements. This could be used to further calibrate an SR function.

Selecting an interim conservation objective could also be based on these data. The data and analysis provide strong support for the current management plan that has resulted in increased estimated escapements over the past five years. Based on the fact that the observed calibration points were low relative to estimated recent escapements and that new observations could increase both the estimates of productivity (α) and maximum production which in turn would increase accepted reference points the 50% of equilibrium was explored. As noted fully 40% of the estimated escapements were above this value suggesting that it is a reasonable benchmark.

However, there is a wide gap between 124 eggs and 187 eggs as explored here. In the case of the Sand Hill River data, that gap is the difference between 2,198 salmon and 3,322 salmon or 1,124 fish for harvest. This is greater than the average harvest and half the harvests in the 1980's. While a manager may want to allocate benefits associated with that harvest it is also in the manager's best interest to ask what future benefits are forgone by over harvesting. A precise answer to these questions can only come with more and better SR data.

ADJUSTED FRESHWATER PRODUCTION APPROACH

The resulting median number of eggs per unit required for conservation based on the adjusted freshwater production method was 152, with corresponding 95% confidence bounds of 80-370. Number of eggs required based on these simulations was 8.08 million (95% confidence interval = 4.25-19.67 million) [number of eggs per unit x number of habitat units]. The median value of 152 is about 37% less than that currently in use for fluvial habitat in insular Newfoundland (240).

Reconciling input parameters: the adjusted freshwater production approach is sensitive to input parameter values. Thus, modifying the range in numbers of smolt produced or estimates of freshwater survival will, obviously, result in different numbers of eggs required such that an increase in the potential number of smolts produced or a reduction in the freshwater (egg-to-smolt) survival would correspondingly increase the number of eggs required to achieve conservation.

Had three (3) smolts per unit of fluvial habitat been assumed for Sand Hill River, then potential production would be in excess of 150 thousand smolts, a value three times greater than that observed at Sand Hill during 1970-73. This, however, appears rather high. However, for a system with a drainage area of 1,155 km^2 (area above the counting fence only) the number of smolts reported (average = 47,100) seems, at first glance, to be low. For example, Campbellton River (SFA 4) has a drainage area almost 4 times smaller than Sand Hill, yet produces, on average, almost as many smolts (Downton et al. 2004). The drainage area of Conne River (SFA 11) is approximately one-half that of Sand Hill, yet the average number of smolts produced at Sand Hill River (1970-73) was only 65% of the mean recorded for Conne River (Dempson et al. 2004).

In trying to reconcile the appropriateness of the range of smolts used, we also considered the numbers of smolts that would have been required to produce the counts of small salmon returning to Sand Hill River for years 2002-05. Here, marine survival varied arbitrarily from 4 to 10%, similar to the range observed for insular Newfoundland stocks where both smolt and adult salmon are monitored. For example, to achieve 3,141 small salmon that returned to Sand Hill River in 2002, 78,525 smolts would have been required had marine survival been 4%, versus 39,263 smolt if survival was 8%, and so on. Thus, over the range of 4-10% survival in incremental units of one for the four years of adult small salmon counts (2002-05), the overall average number of smolts was 67,863 and similar to the initial value used as a starting point (66,000) for this exercise.

Reconciliation of the egg-to-smolt survival values is more problematic. As noted, egg-to-smolt survival based on all year classes for Western Arm Brook averaged 1.39%. Values available for other Newfoundland systems range from 0.52% at Northeast Brook, Trepassey, to an average of 1.22% at Conne River (Klemetsen et al. 2003).

The higher freshwater survival over all year classes recorded at Western Arm Brook (WAB) relative to Conne River and Northeast Brook, Trepassey, has been potentially linked to the greater amount of lacustrine habitat available at WAB (Klemetsen et al. 2003). At Northeast Brook, Trepassey, where the lowest egg-to-smolt survival (0.52%) was noted, the ratio of lacustrine (L) to fluvial (F) habitat (expressed as m^2) was 5.2. At Conne River, 1.22% freshwater survival was recorded where the L/F ratio was 24.1. In contrast, the L/F value for Western Arm Brook is 69.6 where survival was 1.39% (earlier value reported by (Chadwick 1982) was 1.7%). Hence, at Sand Hill River where the L/F ratio is 15.3, egg-to-smolt survival may be closer to a value of 1. In the current exercise we used 0.814% in consideration of the increased egg deposition and smolt production values over the past decade. Thus, reconciling an appropriate range of freshwater survival is not entirely clear.

DISCUSSION

Similar to the SALMODEL project (Crozier et al. 2003a), the purpose of this paper was to:

> ''*Advance the scientific basis upon which advice is given to managers of local, national, and international salmon fisheries, compatible with the precautionary approach, as adopted by the North Atlantic Salmon Conservation Organization (NASCO) and within the requirement of sustainability*''.

As described above, our intent was to develop a scientific basis for the determination of advice to management on Labrador salmon stocks which unfortunately is severely limited by a lack of data. This is because there is no river in Labrador with a sufficient time series of SR data with which to base SR relationships on and determine CLs. The longest time series is from Sand Hill River but because it was broken into three time periods, viz. 1970-73, 1994-96, and 2002-05, no SR time series is available. Also, except for early years, smolt counts are not available from Sand Hill River or any river in Labrador. We have examined six techniques used elsewhere and adapted three of them to the available data from Labrador in the interests of providing CLs based on local stock information rather than using the Eastern Canadian standard which was derived from a river well to the south where the climate is different. Of the three techniques that we chose not to use, (O'Connell et al. 1997) technique provides a total but not an individual CL for use on individual rivers while the technique of Symons is of questionable benefit for Labrador as he used no northern rivers in his analysis. The third technique was based on SR data from a river far to the south of Labrador and was rejected for that reason. Our results provide three possible levels of CLs for Labrador salmon stocks. These are 152 eggs per unit from examination of potential smolt production at Sand Hill River, 161 eggs per unit from a 'hockey stick' SR model approach, and a third possibility of 187 eggs per unit from SR relationships based on angling data and available fence counts. All are substantially less than the standard value of 240.

The default CL established for Canadian rivers of 240 eggs per 100 m^2 of parr rearing fluvial habitat plus an additional increment for lacustrine habitat was clearly interim until such time as more refined estimates became available on a river-by-river basis (CAFSAC 1991a&b). (Dempson and O'Connell 1996) modified conservation requirements for Newfoundland rivers based on the knowledge that salmon parr rear in lakes in Newfoundland. Thus, in addition to the standard value of 240 eggs per unit for fluvial habitat, Newfoundland rivers have an additional increment of 368 eggs per ha of lacustrine habitat added to the CR. In Québec, SR data from six rivers was used to develop CLs ranging from 160 to 182 eggs per unit which combined with a habitat quality index allowed for them to be transported to other rivers with no SR data. (Crozier et al. 2003a) based the results of SALMODEL on 15 sets of SR data to determine CLs for European rivers. Thus, the use of 240 is not sacrosanct in Canada or elsewhere and other values should be used where warranted and available.

There are of course many ways to assess the benefits, costs, and risks of increased spawning escapement. Incorporating parameter uncertainty in that process, such that for a given proportion of times an objective would be met or exceeded (a risk acceptance level), defines one aspect of a precautionary approach that with more modelling could be applied in this case. However, the countering caution to that approach is the concept of forgone harvest. As (Myers et al 1994) state "*The most important criterion for the application of any of the methods described here is whether the threshold estimate is sufficiently conservative without needlessly restricting harvest*".

There obviously is a great deal of uncertainty in our three values so in accordance with the precautionary approach adopted by NASCO, which states that stocks should be maintained above the CLs by the use of management targets, we propose adoption of both a CL and MT for Labrador. The MT should be set relative to the CL but also take into account the uncertainties in the biological data and the vagaries of expected returns and socio-economic concerns. A management target can be regarded as a target reference point, i.e. a stock level to aim for, in order to achieve management objectives. For Canadian salmon stocks, (Chaput 1997) indicates that reference points or levels can be either targets to be achieved or danger zones to be avoided, i.e. threshold values. Fisheries management would have as its principle the objective of ensuring that stocks are sustainable by achieving targets and avoiding danger zones. (Chaput 1997) lists two types of risks:

1 – the risk that yields will fall below the maximum attainable level which is the risk of not attaining a desirable target; and,
2 – the risk that the stock will fall below a minimum size which is the risk of falling below an undesirable threshold or danger zone. This latter risk can lead to recruitment overfishing and stock extinction.

In the light of the above and in consideration of the precautionary principle, we recommend as an interim measure that the method using Sand Hill River angling data with a subsequent result of 190 (rounded value from 187) eggs per 100 m^2 of fluvial habitat be used as the CL from which to develop river-by-river CRs. We equally could have chosen the 152 or 161 values from either of the other two techniques but note that the value of 190 is 21% less than that of 240 eggs per unit used for similar habitat in most of Eastern

Atlantic Canada and insular Newfoundland. Furthermore as a precautionary approach, we also recommend that managers adopt the Eastern Canadian standard of 240 eggs per unit as the management target. The 240 eggs per 100 m^2 MT is set higher to ensure adequate spawning by taking into account the potential for higher removals by man and sources of natural mortality. The Conservation Limit of 190 eggs per unit is the threshold level to be avoided at all costs even to the exclusion of all human-derived sources of mortality to protect the stock. It is worthwhile to note that the three methods give results that are somewhat similar to each other. Hopefully, this will provide managers and user groups with some level of comfort that what is being recommended is not excessive and will avoid the types of risks outlined by (Chaput 1997) while still allowing fisheries to take place as per the comments of Myers et al. (1994). A value of 105 eggs per hectare of lacustrine habitat currently in use for northern Newfoundland and southern Labrador should continue to be used for rivers where juveniles have been shown to rear in ponds in Labrador. However, more investigation of parr rearing in ponds in Labrador is warranted.

There are several good reasons why a different CL should be in use in Labrador than in the remainder of Atlantic Canada. First, the use of the standard of 240 eggs per unit is not universal for all rivers in Eastern Canada, as various values are used in Québec depending on the location and type of river. Caron et al. (1999) point out that climate is harsher to the north in Canada and that habitat varies from river to river partly dependent on size of river. In Québec, the base CL which is measured as S_{opt} from SR graph at the 75^{th} percentile ranges from 145 to 190 eggs per unit (182 median value) depending on the river. (Power 1981) showed degree days (days with mean temperature over 5.6 °C) ranging from 120 in south Labrador to 80 days in the northern part of the salmon distribution. (Elliott 1993) indicated that for brown trout the egg deposition that maximizes total recruitment decreases with the older life stages. (Symons 1979) concluded that rivers with older smolt ages would require fewer spawners. Salmon rearing in pond habitat does not appear important to overall productivity. This may be related to the presence of freshwater fish other than salmonids in Labrador (Black et al. 1986). However, there is not enough data to be conclusive and a study to better define it is warranted. Parr rearing in lacustrine habitat is not included in CRs in Québec and it would be unusual if parr rearing in ponds simply ceased at the border rather than declining with latitude.

Fisheries managers must also be aware of the need for a ‘precautionary approach’ to setting reference levels such that they should be set above biological levels in order to ensure that arbitrarily setting levels too low does not lead to underachieving the actual or true reference level. (Potter 2001) stated that the management of salmon fisheries cannot wait for reference points to be established for every salmon stock. Much progress is being made (e.g. Prévost and Chaput 2001; Crozier et al. 2003; Prévost et al. 2003), and current endeavours by NASCO and some national governments to adopt a precautionary approach to management of salmon stocks provides us with an opportunity to examine the data available for Labrador. In conclusion, we recommend that 190 eggs per unit be adopted as a CL to set CR requirements for rivers in Labrador and that managers adopt 240 as their management target. The habitat production area for Labrador rivers needs to be documented with respect to accuracy of the information, completeness of the surveys and qualification of the habitat. Also the inclusion of spawning requirements for lacustrine habitat would seem to be reasonable given the publications on the subject but it should also be the subject of future research.

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Table 1. Total spawners in year i and parent spawners in year i-5,6,7,8&9 for small salmon and year i-6,7,8,9&10 for MSW salmon for Labrador. Data from ICES 2004.

Year	Spawners in year i			Lagged spawners			Total recruits in year i		
	Small	Large	Total	Small	Large	Total	Small	Large	Total
1969	44647	14692	59339						
1970	60998	14326	75324						
1971	80771	20728	101500						
1972	60454	17812	78266						
1973	6752	24492	31245						
1974	66962	24335	91296						
1975	133904	23123	157026						
1976	90732	26104	116836						
1977	81248	22667	103916						
1978	38818	17963	56781	61642	18173	79815	85616	152386	238002
1979	52263	10087	62350	31010	19135	50146	116290	87253	203543
1980	123824	24697	148521	54570	22015	76586	263236	183704	446940
1981	136248	22482	158729	104105	24069	128175	291730	178651	470381
1982	93883	16424	110307	102010	23616	125626	202107	152603	354710
1983	56605	11901	68506	81664	24645	106309	125771	110067	235838
1984	28626	8336	36962	54356	23480	77836	65097	60625	125723
1985	55308	6667	61975	55013	18893	73906	120475	48773	169248
1986	84591	11525	96116	96730	14025	110755	181621	94794	276415
1987	104961	15578	120539	124539	19398	143938	227558	133447	361005
1988	96978	9446	106424	105629	22108	127737	211418	92952	304369
1989	64982	9315	74297	68717	18416	87133	143692	89285	232977
1990	37424	5271	42696	43038	13545	56583	84016	46077	130093
1991	30691	2664	33355	49873	9668	59542	68094	25514	93608
1992	42979	10568	53547	74393	7703	82096	62716	48333	111049
1993	58020	13799	71819	95539	10122	105661	72659	33327	105986
1994	40023	18867	58890	95404	13491	108894	49002	30134	79136
1995	55235	36380	91615	74798	11357	86155	63699	44789	108488
1996	114219	26915	141134	47144	9198	56342	123218	36904	160123
1997	108625	22639	131264	35276	6562	41837	117374	33075	150449

Table 2. Effort and catch of small and large salmon angled from the SandHill River from 1964 to 2005.

Year	Effort Rod Days	Small (<63 cm) Retained	Released	Total	Large (>63 cm) Retained	Released	Total	Total (Small + Large) Retained	Released	Total
1964	87	44		44	0			44		
1965	116	24		24	32			56		
1966	87	31		31	12			43		
1967	97	14		14	5			19		
1968	100	10		10	26			36		
1969										
1970	115	111	.	111	2	.	2	113	.	113
1971	74	112	.	112	0	.	0	112	.	112
1972	148	219	.	219	10	.	10	229	.	229
1973	272	519	.	519	0	.	0	519	.	519
1974	219	1414	.	1414	201	.	201	1615	.	1615
1975		2524	.	2524	56	.	56	2580	.	2580
1976	66	2337	.	2337	152	.	152	2489	.	2489
1977	0	2244	.	2244	160	.	160	2404	.	2404
1978	127	1243	.	1243	152	.	152	1395	.	1395
1979	351	2312	.	2312	60	.	60	2372	.	2372
1980	561	2158	.	2158	320	.	320	2478	.	2478
1981		2824	.	2824	105	.	105	2929	.	2929
1982	382	1999	.	1999	162	.	162	2161	.	2161
1983	188	1884	.	1884	161	.	161	2045	.	2045
1984	240	1246	.	1246	103	.	103	1349	.	1349
1985	169	1367	.	1367	59	.	59	1426	.	1426
1986	239	1972	.	1972	154	.	154	2126	.	2126
1987	507	2625	.	2625	277	.	277	2902	.	2902
1988	340	2653	.	2653	288	.	288	2941	.	2941
1989	553	2242	.	2242	264	.	264	2506	.	2506
1990	365	1680	.	1680	144	.	144	1824	.	1824
1991	691	1041	.	1041	36	.	36	1077	.	1077
1992	411	1599	158	1757	208	10	218	1807	168	1975
1993	396	1340	1255	2595	114	36	150	1454	1291	2745
1994	499	279	326	605	29	7	36	308	333	641
1995	426	289	340	629	28	14	42	317	354	671
1996	739	321	702	1023	20	36	56	341	738	1079
1997	629	289	472	761	8	30	38	297	502	799
1998	594	208	469	677	8	39	47	216	508	724
1999	694	193	626	819	5	80	85	198	706	904
2000	644	119	814	933	4	58	62	123	872	995
2001	651	127	587	714	0	86	86	127	673	800
2002	651	155	679	834	1	68	69	156	747	903
2003	496	203	608	811	7	60	67	210	668	878
2004	436	109	647	756	1	86	87	110	733	843
2005	559									1266

Table 3. Count of small and large salmon , angling effort, angling catch, catch per unit of effort and estimated catcability (q) by angling as determined at the Sand Hill River counting fence 1970 to 1973, 1994 and 2005.

	Count			Effort	Angling catch: Small (<63 cm)			Angling catch: Large (>63 cm)			Angling catch: Total (Small + Large)				
Year	Small	Large	Total	Rod Days	Ret.	Rel.	Tot.	Ret.	Rel.	Tot.	Ret.	Rel.	Tot.	CPUE(rd)	qrodd(i)
1970	3,600	138	3,738	115	111	.	111	2	.	2	113	.	113	0.98	0.00026
1971	3,484	266	3,750	74	112	.	112	0	.	0	112	.	112	1.51	0.00040
1972	1,901	168	2,069	148	219	.	219	10	.	10	229	.	229	1.55	0.00075
1973	4,584	491	5,075	272	519	.	519	0	.	0	519	.	519	1.91	0.00038
1994	2006	751	2,757	499									641	1.28	0.00047
2005			7886	559									1266	2.26	0.00029

Table 4. Estimates of adult salmon escapements, estimated egg depositions and eggs that contributed to smolt counts with resulting egg to smolt survivals and smolts per escaped salmon for the Sand Hill River 1964 to 2005.

	Adult salmon escapements by CatchPUE/(CatchPUE/CountPUE) based on LogNormal distribution							
Year	2.50%	50%	97.50%	Estimated egg deposition (median value)	Smolt cohort eggs	Smolt count	Egg to smolt survival	Smolts per spawner
1964	2,370	1,134	542	3,392,459				
1965	2,262	1,082	518	3,238,257				
1966	2,316	1,108	530	3,315,358				
1967	918	439	210	1,313,902				
1968	1,687	807	386	2,414,814				
1969	1,910	914	437	2,734,958				
1970	4,604	2,203	1,054	6,591,160	3,167,246	50,494	0.016	48
1971	7,092	3,393	1,623	10,152,372	3,138,038	55,000	0.018	52
1972	7,250	3,469	1,660	10,378,988	2,158,143	37,007	0.017	51
1973	8,940	4,278	2,047	12,799,108	2,100,076	47,724	0.023	68
1974								
1975	12,488	5,975	2,859					
1976								
1977								
1978								
1979								
1980								
1981								
1982								
1983								
1984								
1985								
1986								
1987								
1988								
1989								
1990								
1991	7,303	3,494	1,672	10,454,876				
1992								
1993								
1994	6,019	2,880	1,378	8,616,655				
1995	7,380	3,531	1,690	10,565,600				
1996	6,841	3,273	1,566	9,793,958				
1997	5,952	2,848	1,363	8,520,741				
1998	5,711	2,733	1,307	8,175,858				
1999	6,103	2,920	1,397	8,737,561				
2000	7,239	3,464	1,657	10,363,786	9,418,969			
2001	5,758	2,755	1,318	8,243,094	9,911,958			
2002	6,499	3,110	1,488	9,304,392	9,010,147			
2003	8,294	3,969	1,899	11,873,919	8,401,438			
2004	9,059	4,335	2,074	12,969,473	8,662,567			
2005	10,612	5,077	2,429	15,191,587	9,558,433			

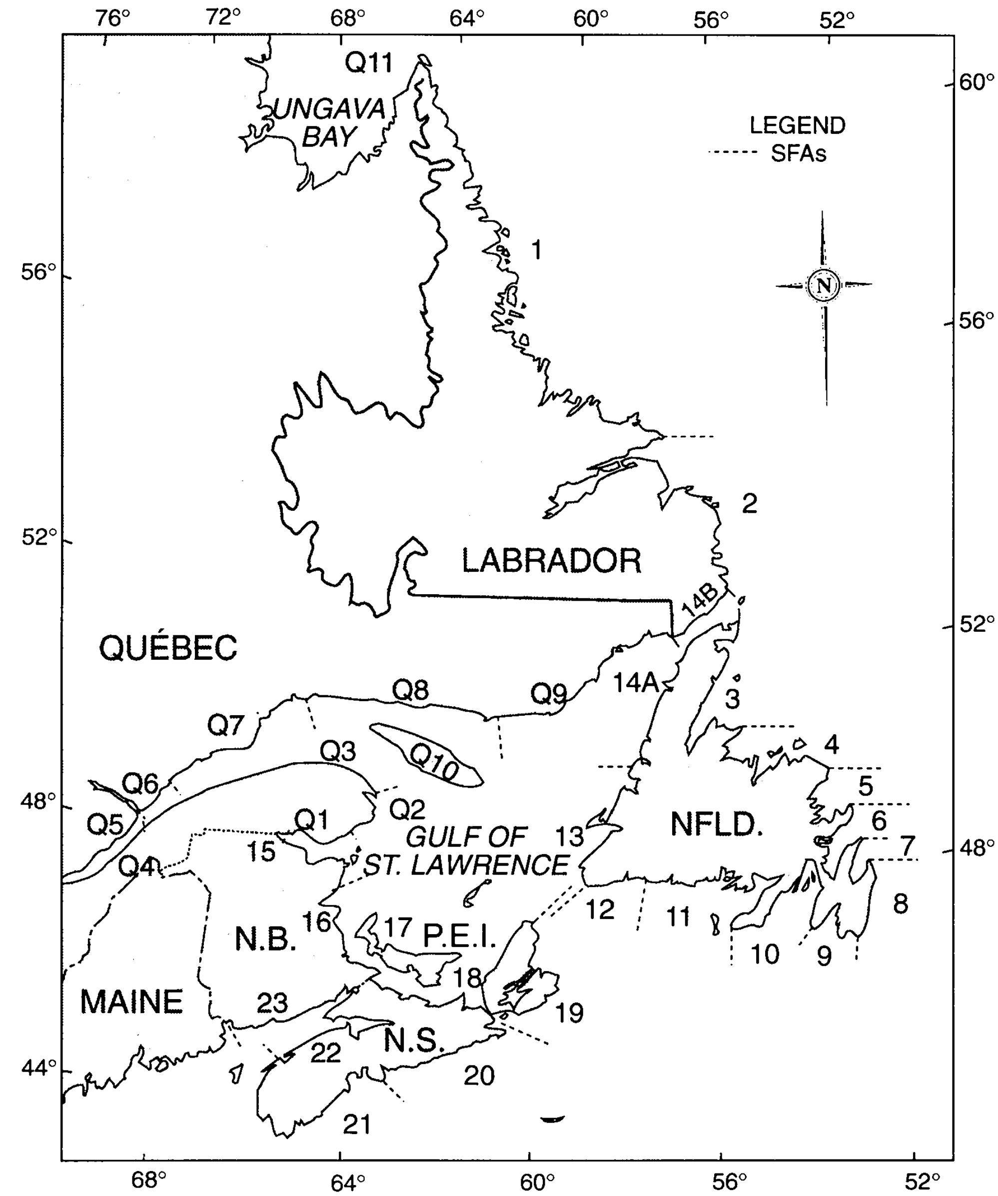

Figure 1. Map of Salmon Fishing Areas (SFAs) and Quebec Management Zones (Qs) in Canada.

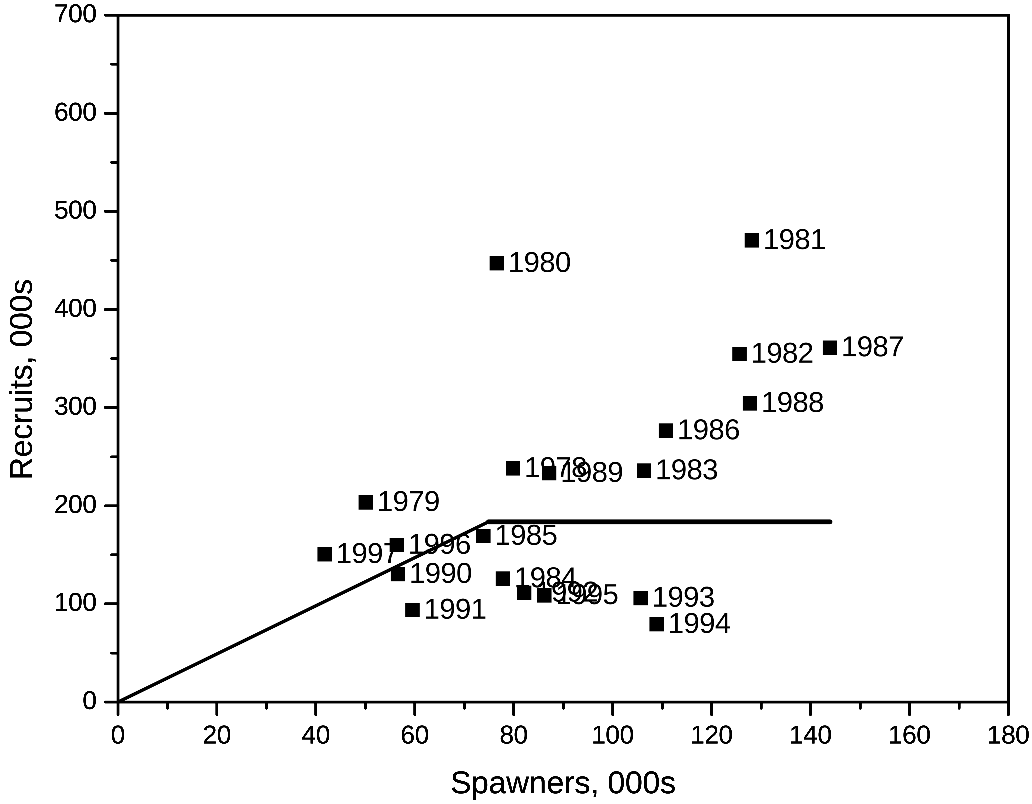

Figure 2. Plot of quasi-stock and recruit relationship for Labrador, 1978-97. Both spawners and recruits are expressed as adults.

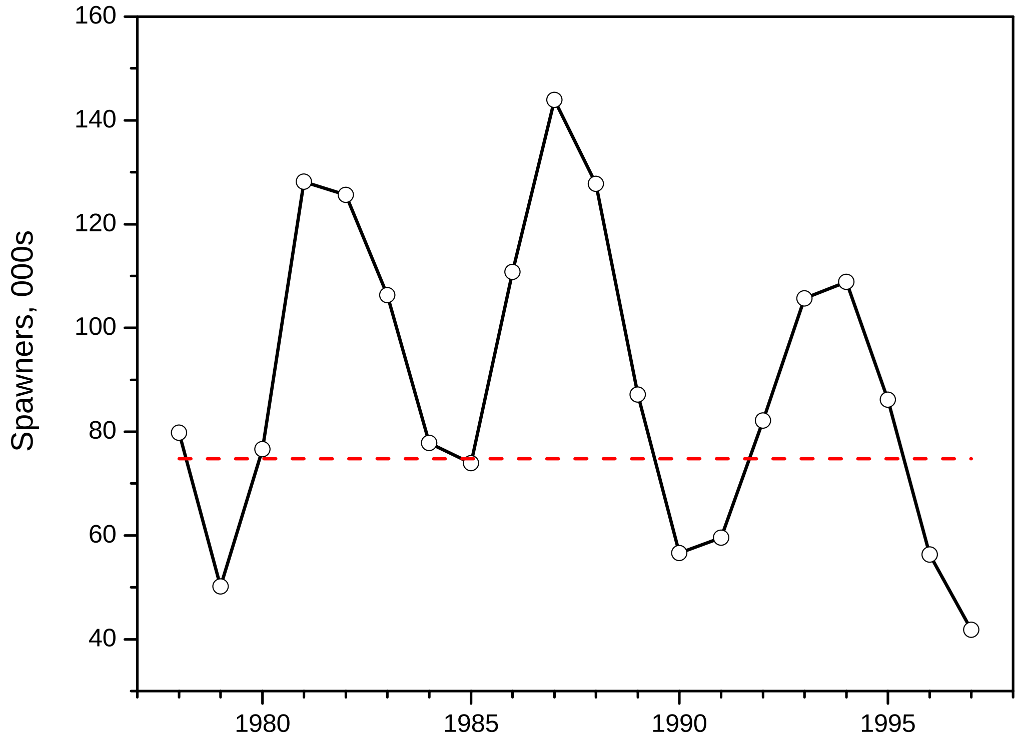

Figure 3. Annual number of spawners in Labrador, 1978-97. Dashed line is the conservation limit.

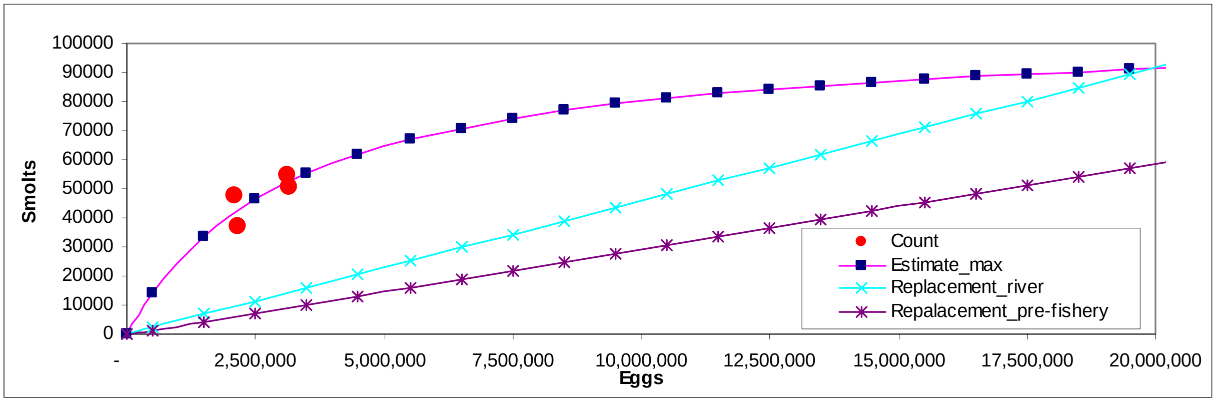

Figure 4. A Beverton Holt stock and recruitment relationship between smolts and cohort eggs shown as both asymptotic and half saturation models. Replacement lines are shown for both the fished and unfished (pre-fishery) population estimates.

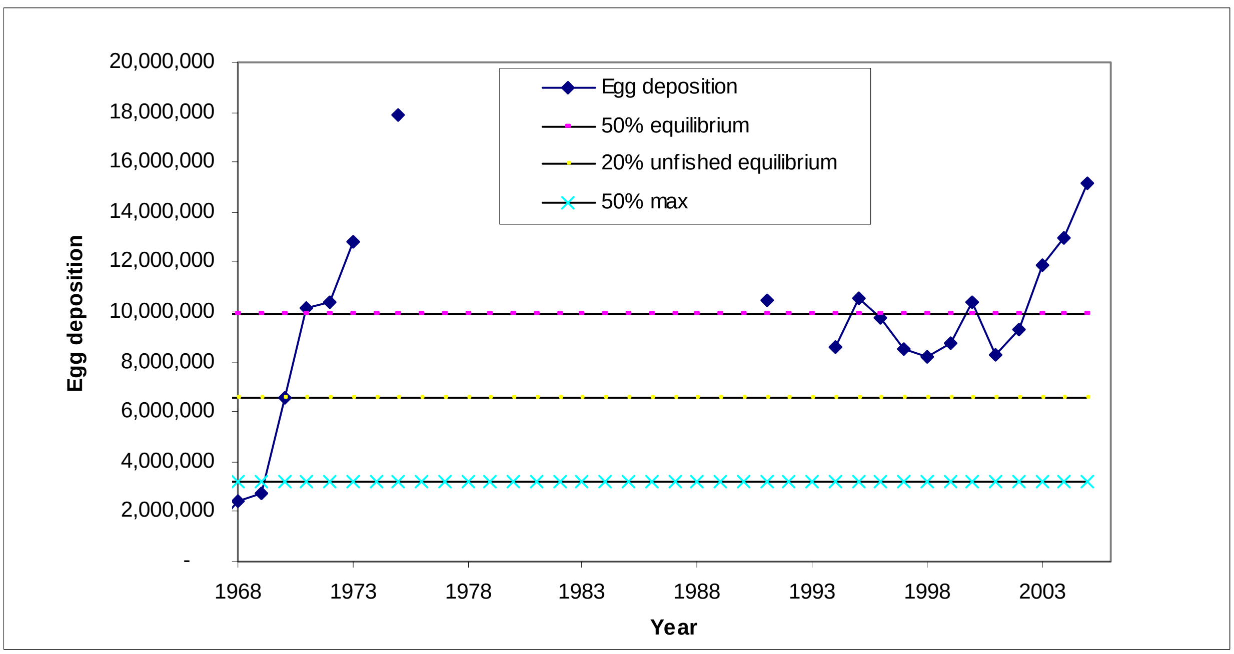

Figure 5. Annual estimated egg depositions in relation to conservation limits at 50% of the equilibrium point , 20% of the un-fished equilibrium point and 50% of the maximum production of smolts based on the egg to smolt stock recruitment relationship derived from smolt counts and egg depositions determined from the angling catch data for Atlantic salmon in the Sand Hill River Labrador, 1968-2005. Estimates were constrained to the 99% confidence interval of the catch per unit effort observed during the fence operation 1970-73.

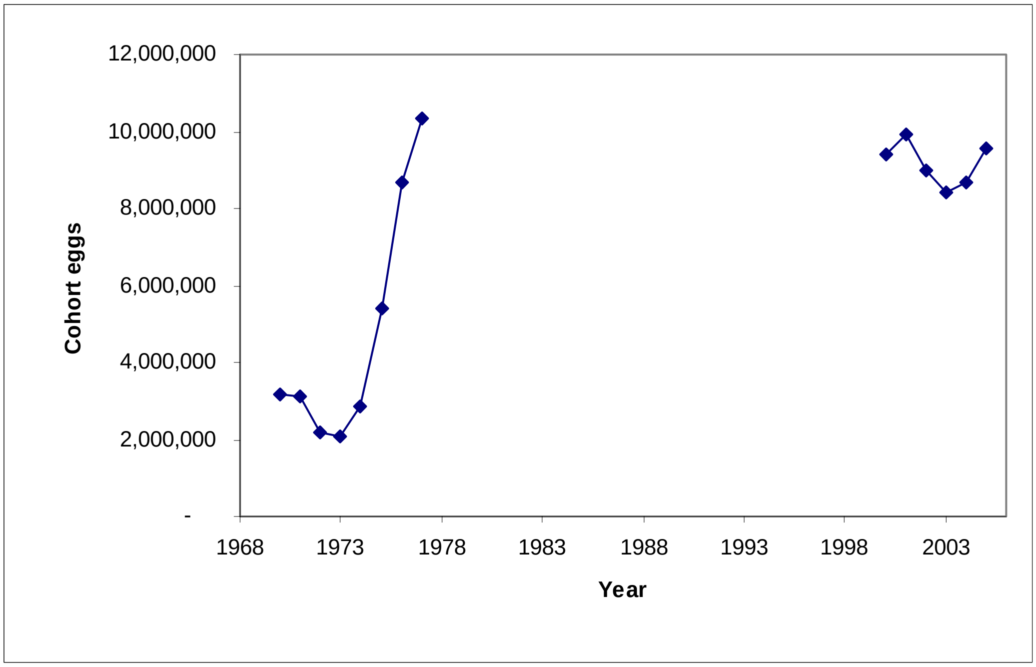

Figure 6. Cohort eggs depositions that contributed to the smolt counts in 1970-73 for the Sand Hill River, and estimates available for 1995-2004 that will substantially contribute to smolts in 2000-09.

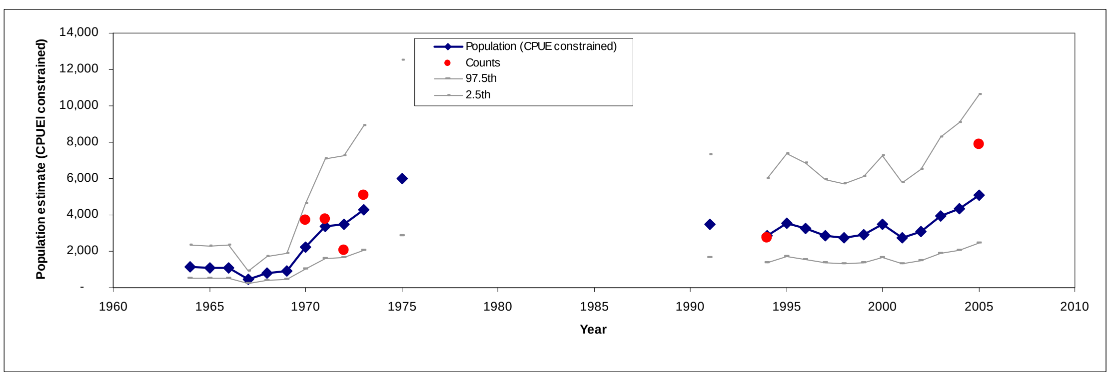

Figure 7. Population estimates for Sand Hill River based on converting catch rates (CPUE) in the angling fishery to population estimates.