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Research Document 2000/062 | **Document de recherche 2000/062**

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Assessment of the status, vulnerability and prognosis for Atlantic salmon stocks of the Southern Upland of Nova Scotia

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ISSN 1480-4883
Ottawa, 2000

Abstract

The status, vulnerability to extirpation, and prognosis for Atlantic salmon (*Salmo salar*) populations of the Southern Upland of Nova Scotia are assessed with respect to the impact of acidification and low marine survival. Management measures involving stocking and pH manipulation to enhance the probability of persistence of the stocks and to provide harvests are numerically assessed. A total of sixty-five rivers was identified where 84.8 million m^2 of salmon habitat remain. Previous categorizations of status and vulnerability indicated fourteen rivers with pH less than 4.7 where populations were extirpated, twenty-four partially impacted (pH 4.7-5.0) and twenty-two low-impacted (pH 5.1) rivers. Analysis of forty-seven rivers, based on mean winter pH in 1985 and 1986 and assumed marine survival of 10%, indicated that 55% or 26 of the rivers would become extirpated. At 5% assumed marine survival, 85% or 40 of the forty-seven rivers will become extirpated. At 5% marine survival even the low pH-impacted rivers will not provide surplus for harvest without enhancement i.e. hatchery supplementation. Hatchery supplementation in pH-impacted rivers without pH improvement was shown to be ineffective. Recent electrofishing has determined that 28% of the rivers fished were void of salmon parr, a proportion that was in close agreement with projections from a model based on mean winter pH. Juvenile population survey and sampling are recommended to further validate the models and to provide tissue samples for genetic analyses that may document population structure among rivers of the Southern Upland.

Résumé

L'état, la vulnérabilité à disparaître et le pronostic des populations de saumon atlantique (*Salmo salar*) des hautes terres du sud de la Nouvelle-Écosse sont évalués en regard des incidences de l'acidification et de la faible survie en mer. Les mesures de gestion engageant l'ensemencement et la régulation du pH afin d'accroître la probabilité que les stocks perdureront et de permettre la pêche sont aussi évaluées en termes numériques. Il reste, dans un total de 65 rivières identifiées, 84,8 millions de m^2 d'habitat du saumon. Des catégorisations précédentes de l'état et de la vulnérabilité ont été identifiées dans des populations : 14 rivières de pH inférieur à 4,7 où les populations avaient disparu, 24 rivières partiellement perturbées (pH 4,7-5,0) et 22 autres peu perturbées (pH 5,1). Une analyse de 47 rivières reposant sur le pH d'hiver moyen en 1985 et 1986 et un taux supposé de survie en mer de 10 % a révélé que 55 % ou 26 de celles-ci verraient leurs populations de saumon disparaître. À un taux supposé de survie en mer de 5 %, ce sont 85 % ou 40 des 47 rivières qui verraient leurs populations disparaître. À ce taux, même les rivières peu perturbées ne produiront pas d'excédents de saumon à pêcher sans une mise en valeur, c'est-à-dire un apport de poissons d'écloserie. Il a été démontré que le déversement de poissons d'écloserie dans des rivières au pH perturbé sans bonification de ce dernier est inefficace. Une récente pêche à l'électricité a révélé qu'aucun tacon n'était présent dans 28 % des rivières échantillonnées, un pourcentage se rapprochant des prévisions issues d'un modèle fondé sur le pH d'hiver moyen. On recommande de faire des relevés et des échantillonnages des populations de juvéniles afin de valider davantage les modèles et d'obtenir des échantillons de tissus aux fins d'analyses génétiques, qui pourraient permettre de documenter la structure des populations dans les rivières des hautes terres du sud de la Nouvelle-Écosse.

Introduction

Distribution and abundance of Atlantic salmon (*Salmo salar*) has declined in rivers along the Atlantic coast of Nova Scotia since European colonization (Dunfield 1986). Causes for declines have ranged from acute effects, e.g. dams, and polluted effluents, to widespread chronic loss due to habitat degradation, e.g., industrial development and acidification (Watt 1989).

Increased attention to these declines has resulted in changes to acts and policies concerning the interpretation and application of the Fisheries Act, the principal legislation protecting fish resources in Canada. These changes have been documented since 1884 when remedial actions were required for milldams and sawdust dumping into Nova Scotia rivers (Venning 1885). Beginning in the late 1920's hydroelectric development further eroded the salmon productive capacity of Nova Scotia rivers through the construction of high-head dams on some of the largest drainages within the province, e.g. Tusket River, Mersey River, East River Sheet Harbour. Watt (1989) estimated that about 17±5 % of the productive capacity for Atlantic salmon in Canada has been lost since 1870. Much of this loss has occurred in the Maritimes and particularly in Nova Scotia.

Early technology to mitigate obstructed fish passage was primitive and both upstream and downstream fish passage devices, even when installed during construction, were not effective. Also, because fish passage is always less than 100% efficient, the impact of a series of dams acts like a damper on fish populations, further reducing productive capacity. The advent of improved fish passage technology has led to the reconstruction of many facilities. However, habitat lost to flooding of river channels by these dams cannot be recovered without removal of the dams. Even if all dams were removed recovery of productive capacity for Atlantic salmon may be unlikely because of the time required to develop locally adapted salmon populations. Consequently, recovery of productive capacity is difficult, and the future stability of salmon populations is thought to lie in protecting the remaining fish and habitat. Even though a "no net loss" policy for habitat management in Canada is being followed and commercial and recreational salmon fishing is restricted or closed, populations of Atlantic salmon have continued to decline.

Lower marine survival has been suggested as an explanation for the general decline in recruitment of North American salmon. Declines in survival since 1988 of hatchery-reared smolts has been noted (Harvie and Amiro 1996, Amiro and Jefferson 1997, Amiro *et al.*1998 and 2000, Marshall *et al.* 1999). Low marine survival of wild smolts migrating from the LaHave River (Amiro *et al.* 2000) and the Conne River, Newfoundland, (Dempson *et al*. 1998) relative to historic values have also been noted. Despite almost complete closure of distant interceptory and local marine salmon fisheries, survival of wild smolts throughout North America has declined since 1987. Historically return rates ranged from 6 to 15% for Newfoundland rivers and from 8 to 10% for Maritime rivers. Since the almost complete closure of the directed salmon fisheries river return rates now approximate marine survival rates. Recent estimates of marine survival for both areas range from 1 to 8% (Anon. 1998). The trend to lower marine survival of smolts may have important implications for the stability and persistence of salmon populations in low-productivity and particularly acid-impacted rivers such as found on the Southern Upland of Nova Scotia.

The susceptibility of Atlantic salmon populations to acid precipitation in rivers of the Southern Upland is well documented (Lacroix 1985, Watt 1987, Farmer *et al*. 1989). A model to assess the effects of changes in acidification on Atlantic salmon in these rivers (Korman *et al*. 1994) indicated that, while unaffected (non-acidified) populations were stable at productivity greater than 10.6 smolts per spawner, salmon populations in some acidified rivers were shown to be not sustainable. The number of non-sustainable populations was dependent on the average marine survival values used in the projections. In that modeling exercise, sea survival was expected to average 10% after accounting for early marine mortality based on smolt size. In acid-precipitation-affected rivers, productivity was reduced to 5.0 smolts per spawner or less. Clearly, if marine survival is consistently less than 10% then the probability of extirpations or extinction for low productivity and acid-impacted rivers is greater than that proposed by Korman *et al.* (1994).

The purpose of this analysis is: 1) to document the present status of Atlantic salmon stocks in rivers of the Southern Upland of Nova Scotia, 2) to assess the sustainability of these stocks in relation to the recent 15 years of low marine survival, and 3) to evaluate management methods and techniques that may enhance the persistence and provide harvests of salmon in the rivers of the Southern Upland of Nova Scotia.

Description of area

The Southern Upland of Nova Scotia (Figure 1) is a physiographic area comprised of slates, greywacke and granite rocks in the southwestern half of the province. The Southern Upland slopes from an altitude of about 275m along its northern margin to sea level and undersea out to the margins of the Scotian Shelf (Roland 1982). The Southern Upland accounts for about one half of the total area of the Province of Nova Scotia. Rivers of the Southern Upland generally drain lowland areas of shallow soils and peat bogs underlain by granites and metamorphic rocks lacking in base minerals (Watt 1987). Water is generally organic-acid-stained, of lower productivity, and, when combined with acid precipitation, can result in toxic conditions for salmon (LaCroix 1985). Interspersed are areas of limestone-rich soils (drumlins) that provide local areas of less-acidified water.

Description of the rivers

Physical habitat

Atlantic salmon rivers in Atlantic Canada have been grouped by the Department of Fisheries and Oceans (DFO) for management purposes into twenty-three Salmon Fishing Areas (SFA) based on similarities of biological characteristics, catch histories and geographical proximity. Nine of the SFAs are within Maritimes Canada (Figure 2). In Nova Scotia two of these salmon fishing areas, SFA 20 on the Eastern Shore and SFA 21 on the South Shore, occupy the area geologically known as the Southern Upland of Nova Scotia.

The number of rivers in these areas that historically produced Atlantic salmon is unknown but at least 65 rivers are suspected of once maintaining Atlantic salmon populations (Figure 1, Table 1). Salmon production since 1985, as indicated by reported recreational catch, includes about forty rivers (O'Neil *et al*. 1998).

The salmon production area for 48 (included Little West River Sheet Harbour) of the Southern Upland (SU) rivers was measured from aerial photographs and ortho-photographic maps using the method of Amiro (1993) (Table 2). This method identified and measured 84.8 million m^2 of stream area from Salmon River, Digby, to Cole Harbour River, Guysborough County. Seventeen of the smaller rivers and some larger rivers that are hydroelectric-impacted, e.g., Mersey River, that are included in the list of potential salmon rivers were excluded from the remote-sensed habitat survey. In the SU rivers 29% of the potential salmon habitat area (lakes excluded) have a stream gradient less than 0.12%. Habitats with stream gradients less than 0.12% were shown to produce few Atlantic salmon parr (Amiro 1993) and are therefore considered marginal juvenile Atlantic salmon habitat. Only 16% of the salmon habitat areas had stream gradients of 0.5 to 1.49%, which is considered potentially prime habitat for juvenile Atlantic salmon (Elson 1975, Amiro 1993).

Acidity (pH)

Rivers with mean annual pH less than 4.7 are not likely to support Atlantic salmon. Watt (1987, 1997 and Watt *et al.* 2000) lists fourteen rivers of the SU that have mean annual pH < 4.7 and are known to have lost their salmon populations (Table 3). In rivers with mean annual pH above pH 4.7 but below pH 5.1, salmon production is considered unstable and only remnant populations may persist (Watt 1987). Watt (1997) noted that on the Southern Upland of Nova Scotia some twenty rivers have salmon stocks that are partially impacted by acidification. Partial impact was concluded where the main-stem mean annual pH was between 4.7 and 5.0.

Salmon in rivers with mean annual pH equal to or greater than 5.1 may be low or not impacted by pH effects. Watt (1987) classified fourteen low- or non-acidified salmon rivers in SFA 20 (Gaspereau Brook, West River Sheet Harbour, East River Sheet Harbour, Port Dufferin, Halfway Brook, Ecum Secum, Quoddy, Moser, Ship Harbour Lake Charlotte, Country Harbour, St. Marys, Salmon Guysborough, Musquodoboit and Guysborough rivers) and eight rivers in SFA 21 (Gold, LaHave, Medway, Martins, Meteghan, Mushamush and Petite Riviere). These rivers have a history of Atlantic salmon angling catch and had pHs greater than or equal to 5.1 as recent as 1986.

Water quality in rivers of the Southern Upland of Nova Scotia has deteriorated or at least is unimproved since 1986 (Watt 1997, Watt *et al*. 2000). This has not been the trend elsewhere in North America and Europe where increases in alkalinity have been noted with declines in air emissions and subsequent declines in acid deposition.

Impoundments

Some rivers of the SU are also impacted to various degrees by impoundment for hydroelectric, domestic or industrial water uses. These rivers include Tusket, Roseway, Jordan, Mersey, Medway, Petite, LaHave, Indian and Northwest (St. Margaret's Bay) and East River Sheet Harbour.

Description of the salmon stocks

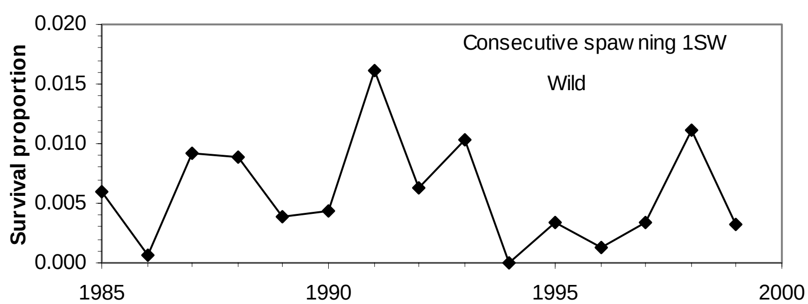
Stock characteristics

The majority of Atlantic salmon of SFA 20 and 21 migrate to the sea as two-year smolts and are characterised by returns of mixed age-at-maturity salmon. Fish that mature after one winter-at-sea (1SW salmon, small salmon or grilse) comprise about 80% of the fish and are about 40% female. On average, 1SW and two-sea-winter (2SW) salmon in these rivers contribute equally to egg depositions.

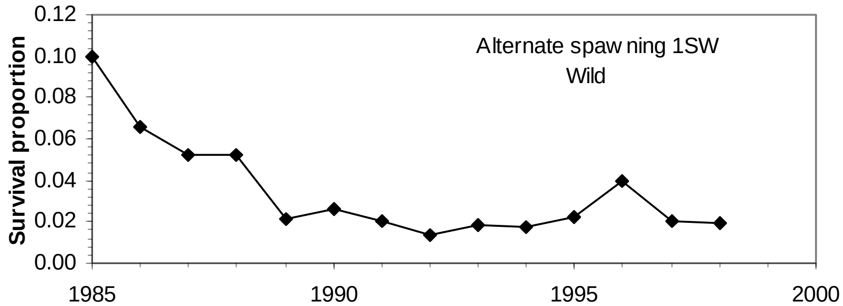
Historically there were exceptions to this stock generalization, notably, Tusket River, East River and St. Marys River (Anon 1978, Marshall 1986). Stocks in these rivers were noted for large salmon, some of which were identified to be three-sea-winter salmon. Aging of salmon in recent returns to counting facilities and in-river assessments indicates that most stocks have shown higher proportions of salmon returning after one sea-winter than previously observed. Incidences of multiple-spawning salmon have also increased in some, but not all, rivers.

In 1999 in the St. Marys River, the proportion of one-sea-winter salmon in the spawning escapement was 74% of the run and contributed 55% of the egg deposition. The proportion of 1SW salmon in the run in 1999 was not unlike that observed in 1972 to 1981 (Marshall 1986). The incidence of repeat-spawning grilse in the spawning escapement increased, however, to 15% in 1999 from an average of 7.3% observed from samples obtained from 1972 to 1981.

In the LaHave River at Morgans Falls the proportion of wild virgin (recruit) grilse that return as consecutive-spawning grilse the following year has varied from 0 to 15 % since 1985 (1SW-recruitment year). The proportion peaked in 1991, fell to zero in 1994 and increased to about 10% in 1998, as in the graph below.



While this instability is also present for the alternate-spawning group, (post-spawning fish that remain at sea for a year before returning to spawn again) the proportions of alternate-spawning 1SW salmon range from 1 to 6%. The proportion declined from 1985 to 1989 and with one exception (1994) has remained at about 2%.

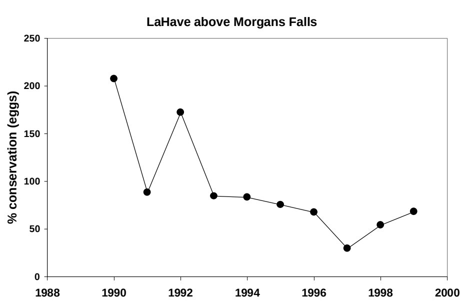


These data suggest that for some SU rivers the potential decreases in egg deposition attributed to decreased smolt survival have not been offset by an increased incidence of repeat spawning.

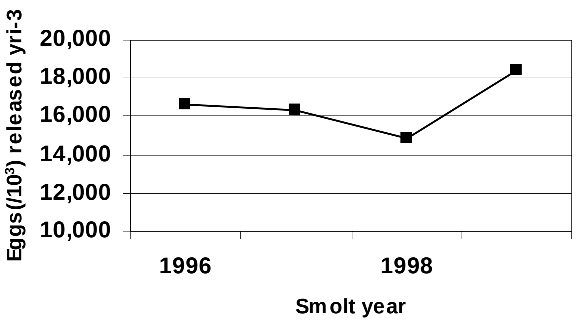
Status of the stocks

Status of the salmon stocks of Salmon Fishing Areas 20 and 21 are assessed annually. Results are published in Canadian Stock Assessment Research Documents and summarized in Stock Status Reports for Atlantic salmon. Because of the uncertainty of appropriateness of standard conservation targets applied to low productivity rivers subject to acidification, only the LaHave River above Morgans Falls and the St. Marys River have operational conservation requirements for salmon. A fishway and a downstream fish counting facility at Morgans Falls provide information to assess the status of the stock above Morgans Falls. The counts of salmon at Morgans Falls are used as an index of the status of salmon for low-acid-impacted rivers of the Southern Upland. The validity of this index is based on the significant correlation among recreational catches for SU rivers and the counts at Morgans Falls (Amiro *et al.* 1996, 1997, 2000; Marshall *et al.* 1999; O'Neil *et al.* 1998). Performances of the other rivers in the SU are expected to correlate with the LaHave River where differences in populations are dependent on relative productive capacities and stocking rates.

Corroborative information is also gathered at other locations, e.g., fishways (Tusket, East River Sheet Harbour, and Liscomb), through periodic in-river population estimates by mark-and-recapture techniques (Tusket, Musquodoboit and St. Marys), by quantitative electrofishing (LaHave, Musquodoboit, St. Marys), qualitative electrofishing (see Table 8), log book angler reports, and through Nova Scotia Salmon Angler License stub reports.



Relative to the operational conservation target of 1,320 fish above Morgans Falls, the LaHave River has not met the conservation requirement since 1992. This decline in recruitment of wild salmon was closely matched by a decline in marine survival of hatchery smolts beginning about 1983 (Figure 3).



The numbers of eggs released above Morgans Falls, 1993 to 1996, were 1.66, 1.63, 1.48 and 1.84 million. Counts of smolts declined from 20,500 in 1996 to 10,400 in 1999, about a 50% decrease (Figure 4). Egg to smolt survival was 1.2,1.0,1.1 and 0.6%, 1996 to 1999, (see Figure 5). These data indicate that the decline in smolts was not only the result of a decline in survival of eggs to smolts in the first three years, but was also associated with the a higher egg deposition. The reasons for the 1999 low egg to smolt survival are not deductible without a cohort (age based) analysis for all years as well as analysis of the accompanying environmental information.

Counts of wild salmon at other fishways (Tusket River, East River Sheet Harbour, Liscomb River), adult salmon population estimates for the St. Marys River and densities of parr in some rivers e.g. St. Marys, East River Sheet Harbour have also declined over the same time period (Amiro *et al.* 1998, Amiro *et. al.* 2000).

Fisheries

Advice to management concerning harvest fisheries is provided in the form of pre-season forecasts of salmon returns to the LaHave and St. Marys rivers. Based on these forecasts and on recent performance of the stocks, harvest fisheries have been reduced to limited catch-and-release fisheries or to complete closures to all salmon fisheries since 1996. In some instances, e.g., Liscomb and East River Sheet Harbour rivers, populations have declined to less than the broodstock required to maintain a salmon run based on hatchery supplementation (Ryman and Laikre 1991). Advice to fisheries management concerning the probable end-of-season population is provided every two weeks after June 15 in the form of in-season forecasts based on cumulative counts at Morgans Falls.

Productive capacities

Past and Present

Based on estimates of the drainage areas and calibrations with recreational angling catches, Watt (1989) estimated that the SU of Nova Scotia had a pre-acidification production potential of about 45,200 adult salmon per year. Watt (1989) also estimated that the production of salmon in 1986 was 22,700 salmon per year. The 50% loss was attributed to acidification. An estimate of the annual loss since 1950 based on drainage area, changes in mean annual pH and angling catches was 5,600 fish (Anon. 1988).

An independent technique based on mean October to April (mean winter) pH and remote-sensed habitat surveys of 47 rivers of the SU estimated a 24% loss in smolt production capacity from 1955 to 1986 (Amiro *et al*. unpublished manuscript 1988). Minimum annual losses to Canadian fisheries and spawning escapements, attributed to acidification, were 2,000 to 8,000 adult salmon, from 1981 to 1983. Concurrent with this loss in productive capacity was also the requirement for a 38% increase in the spawning escapement required to produce the optimum number of parr for the river. This increase in spawning requirement represented a 39% loss in surplus yield, i.e., and potential harvest. A summary of the implications of this analysis stated the severity of the acidification impact (Amiro *et al*. unpublished manuscript 1988).

> "Surplus yield per spawner declined from 3.38 to 1.68. Complete loss of production occurred in eight rivers, and ten additional rivers indicate no surplus yield. Nine other rivers had a value less than one. Any non-discretionary harvest on these nineteen rivers raises the possibility that salmon populations on these rivers will be or have been demised."

These projections were based on an assumed 10% return to Canadian waters. However, a 50% decline in average marine survival could result in more than a 50% decline in surplus yield. Also, consistently low marine survival will result in an increase in the number of rivers where recruitment is less than population replacement, which can lead to extirpation/extinction. Because of the spatially variable geology, extirpation/extinction is not certain. When a river population decreases, the more productive areas in the river (areas impacted by local geological deposits) may continue to produce at rates above replacement. However, the small size of these residual populations makes them vulnerable to random effects. Negative random effects include behavioral effects, e.g., Allee effects (Allee 1931) and/or demographic effects, e.g., variations in fecundity, sex ratios etc. Such effects can lead to further declivity in a population.

The Acid Rain Study Group of ICES (Anon. 1988) reviewed the methods of Watt (1989) and the methods of Amiro *et al.* (unpublished manuscript) and concluded that the second approach was insufficiently developed to calculate actual production losses. The Study Group encouraged further development of the model and publication of the method. The model was subsequently developed further and published as the Atlantic Salmon Regional Acidification Model (**ASRAM**) (Korman *et al.*1994). ASRAM is a dynamic computer-based simulation model of Atlantic salmon life history that uses river-specific habitat, chemistry, survival, and age structure. The model allows management actions to be input and provides annual population output trajectories as well as a variety of signals of the population status.

Moving forward

The ICES Acid Rain Study Group (Anon 1988) recognized that the only satisfactory solution to the acidification problem was the elimination of the source of the acidity. The group concluded that major effort in North America should be devoted to the prevention of additional damage to existing Atlantic salmon stocks and habitat rather than directing effort toward mitigating damage after it occurs. The group also concluded that the methods presented were insufficiently developed at that time to calculate change in productive capacity attributed to acid precipitation. Therefore, the group provided no quantitative retrospective or prognosis for SU salmon. In the interim, the group recommended that vulnerability be monitored through measures of alkalinity for each river system. Development of a tool to measure or assess vulnerability was recommended.

In Canada the 1985 Eastern Canadian SO_2 Control Program was established to reduce acid emissions. In 1990 the Clean Air Act of the United States was enacted and a schedule for reduction in atmospheric pollutants was proposed. The ASRAM model was developed to assess the impacts of these acts on the production on salmon. However, application of the impact-modeling tool (ASRAM) was hindered by the chemical data requirements of the model and therefore no further quantitative estimates were output. Problematic was the development of a water chemistry model to estimate river pH from acid rain depositions. River pH information is required to estimate juvenile salmon mortality within ASRAM. This problem arose in part because the projected change in pH did not follow the reduction in emissions as anticipated. Recent explanations for this delay in recovery (Stoddard *et al.* 1999 and Watt *et al.* 2000) may allow the advance of chemistry models that can interpret salmon toxicity from deposition (precipitation). In the interim, application of the ASRAM model requires extensive local pH sampling to provide population projections.

The sensitivity of interpretations developed from ASRAM projections to spatial and temporal distributions of pH data has been addressed (LaCroix and Korman 1996). Toxicity in ASRAM is calculated from weekly pH. Low pH episodes can occur and recover in less time than a week and models that convert periodic water chemistry to weekly pH were not sensitive enough to detect brief toxic episodes. Therefore, without daily pH data, output (annual population trajectories) of the model is potentially positively biased. Thus projections from the model run with weekly pH data are "best case" outputs for the observed pH information. Interpolated weekly pH data increase the opportunity for this bias to occur.

Sensitivity of model output to spatial resolution of the pH data is difficult to interpret because the minimum viable population size for Atlantic salmon is undetermined. Suggestions are that populations as low as fifteen adult salmon can, in a time frame of thirty years, remain viable (e.g., Cove Brook, Maine, King *et al.* 1999). Because ASRAM works on a reach basis, defined by 5-m elevation contour intervals defined from 1:10,000 orthophoto maps, it is expected to be of a finer resolution than that required to support a population of 15 adult salmon. At 20 smolts per spawner, 1.0% egg-to-smolt survival, 2,000 eggs per spawner and 5% marine survival, about 30,000 m^2 are required to support a population of 15 adult salmon. This amount of salmon production area would be approximately accumulated at the level of the chemistry specified in the models applied here. Therefore, outputs of ASRAM projections are likely to detect significant refuges for salmon.

Methods used to provide salmon population prognoses

Three methods were used to assess the prognoses for salmon populations within rivers of the SU:

1. Outlook for year 2000

The Stock Status Report (DFO 2000) for Atlantic salmon summarized expectations for year 2000 returns. These forecasts are reported here as short-term outlooks for the LaHave and St. Marys rivers and for groups of rivers in three pH classifications.

2. ASRAM simulations

Simulations for two rivers, LaHave River and Liscomb River were run in ASRAM to assess the impacts of acidity and low marine survival on the population stability. These rivers were selected because they represent a low-impacted (Watt category 3) and a more-heavily-impacted river (category 2). Biological information for these rivers is available from traps operated in fishways in both rivers for over twenty years. Recent water chemistry data for these rivers were also available.

A water-sampling program initiated in 1996 for six rivers of the SU was designed to be minimally sufficient to provide input to the pH toxicity component of ASRAM. The results (LaCroix and Knox, MS 1998) indicate unimproved pH conditions in six river systems of the SU of Nova Scotia. Data from two of these rivers, LaHave River and Liscomb River, were used in this analysis to provide schedules of weekly pH in ASRAM projections for these rivers. These pH schedules were used to assess the prognoses of population size, potential yield and probability of stock persistence based on 10% average marine survival as estimated in 1986, and 5% marine survival which is consistent with recent observations.

Chemistry data for the area above Morgans Falls were the same as that reported by Korman *et al*. (1994). Initial ASRAM setup files differed from those used by Korman *et al*. (1994). The differences were: 1) Density-dependent smolt survival was set to a maximum of 10%, i.e., a 15.5 cm fork length smolt would survive at 5%. 2) Reduced marine fishing moralities were applied to two and three-sea-winter salmon at sea. 3) Freshwater mortality of adult salmon was set at 10%.

Weekly pH schedules for areas below Morgans Falls were derived from mean pH (by transformation to H^+ normality) at sample locations for six sample dates. The data were grouped by streams for lower stream orders or by axial grouping for higher stream orders i.e. main-stems. Weekly pH was assumed constant until the next sampling occasion. Streams without pH samples were assumed to be the same as the most proximate tributary stream.

ASRAM projections were run for 25 years. Plots of six indicators were examined to assess the prognosis for the river. These indicators were annual totals of juvenile salmon, smolts, spawners, and smolts per spawner, early marine survival and pH-driven mortality. The stock recruitment module was then run using the same parameter values. The SR module runs to equilibrium across a range of fixed egg depositions. The plots of the loci of equilibrium values of spawners and recruits were then used to estimate values for management objectives such as, maximum sustainable yield and recruits per spawner at first egg increment i.e. slope or α value in a Ricker stock-and-recruitment function (Ricker 1975). All eggs were included in the spawning escapement i.e. eggs from repeat spawners as well as recruit spawners. These management parameter values were then used to indicate a prognosis for the stock for a set of conditions, such as changed acidity, stocking, or marine survival maximums.

In cases where returns did not exceed spawners the SR module was not run. However, ASRAM was run in the Monte Carlo mode to assess the probability of extirpation/extinction. One hundred twenty-five-year projections were run with random variation and temporal trends in marine survival. The number of simulations ending in no population was used as an indicator of the probability of extirpation/extinction.

3. Projections based on mean winter pH

Because complete spatial and temporal water chemistry data were not available for the remaining rivers of the SU, a model was used to assess the productive capacity status. This deterministic model was the precursor of ASRAM and was used by Amiro *et al.* (unpublished manuscript). The model was based on river-specific optimum parr densities and mean winter pH. This model essentially estimates the stability point reached by ASRAM run at a fixed pH.

This deterministic model uses the gradient of each reach to estimate an optimum parr density for the entire river based on the sum of all reaches. Optimum densities were determined by calibration to maximum parr densities observed in the best quality habitat ($\cong$ 1.0 % stream gradient) in non-impacted rivers (LaHave River). The purpose of this calibration was to adjust productivity for limits other than those implied by physical habitat. Parameters for the parr distribution function of Amiro (1993) were derived using this point and a range of gradients. The integral of the parr distribution function evaluated between 0 and 11% gradient; the effective range of juvenile salmon distribution, was equivalent to 7.7 total age-1^+ and age-2^+ parr per 100 m^2.

The function was:

$$\text{Total parr} = 0.5355 * \mathbf{X}^{5.1854} * \mathbf{e}^{-\mathbf{X}}$$

Where **X** = area-weighted surface grade (AWSG) determined from the orthophoto maps. The formula for stream gradient conversion was:

$$\text{Arcsine (AWSG)} = 2.94 * \text{Ln(Arcsine Map grade)} - 0.3128$$

The maximum expected density by this model would result in 14.9 total parr per 100 m^2 in ideal habitat (gradient of 1.0% AWSG). This estimated maximum density is low compared to many rivers and reflects the lower productivity of SU rivers. Based on a length vs. density function from the Stewiacke River (Korman *et al.* 1994), populations at these densities are expected to produce about 75 to 80% two-year-old smolts. In this model age-1^+ parr are expected to become two-year smolts if they reach 9.6 to 10.0 cm in the second summer. Optimum parr densities by this method are therefore dependent on habitat and a growth objective (proportion that smolt at age).

Smolt production was therefore based on the parr population at the expected smolt age structure. Spawning escapement was determined by estimating the eggs required to produce the parr population and a value of 2,094 eggs per fish, an average rate determine from the LaHave River up to 1988. Survival from egg to parr was dependent on pH. The pH used in this analysis was mean October to April pH determined in 1985 and 1986 for rivers of the SU (W.D. Watt [1] pers. comm. and Watt *et al.* 1996).

The pH-driven survival function was determined from data published by LaCroix and Townsend (1987) and first used by Amiro *et al*. (1988). The function was:

$$\% \text{ Survival (egg to age-}1^{+}\text{ parr)} = 5.47 * \text{pH} - 25.07, [R^2 = 0.99, n=4, p < 0.01]$$

Yield to Canadian waters was originally estimated using a marine survival value of 10% determined from LaHave River tagged smolts and recovery information. Projections here were also made using a marine survival value of 5.0%. This value is greater than that currently observed for wild smolts in the LaHave River, 1996 to 1998, (2.03%, 1.9-2.16%, 5^{th} and 95^{th} percentiles, Amiro *et al.* 2000).

Status of stocks by this method was assessed by evaluating the value for surplus yield per spawner at the spawning escapement that attained the optimum parr density for each river. Results were used to classify rivers as extirpated/extinct, endangered, threatened or sustainable. *Extirpated/extinct* rivers cannot produce smolts. Recruits per spawner less than 1.0 are expected to have been extirpated/extinct or are *endangered* of becoming extirpated/extinct. Yields greater than 1 but less than 2 were classified as *threatened* and rivers greater than 2 were classified as *sustainable*.

Status	Criteria
Extirpated/Extinct	No smolts produced
Endangered	Recruits/Spawner <1
Threatened	Recruits/Spawner 1 to 2
Sustainable	Recruits/Spawner >2

Validations

Results from the ASRAM outputs were compared to the deterministic projections using mean winter pH. Where available, field observations of parr presence, parr densities and adult counts were also used to validate the analysis.

Results

Outlook for 2000

Low- or non-acidified rivers (pH ≥ 5.1)

Based on the average estimated return to the St. Marys River of 1,280 small salmon (340 - 2,310) and 340 large salmon (65 – 675), 1995 to 1999, there is less than a 5% chance that the returns in the year 2000 will exceed the conservation requirement of 2,415 small and 713 large salmon.

Forecasts developed from adult cohorts and smolt counts for the LaHave River above Morgans Falls suggest a 35% chance that year 2000 returns will be greater than the conservation requirement. Also, about a third of the forecast return is expected to originate from 46,000 hatchery smolts stocked above Morgans Falls in 1999. However, forecast hatchery returns may be overestimated considering that return rates for hatchery smolts have declined in the past three years and the forecast is based on the previous five-year average return.

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Based on the number of wild smolts emigrating from above Morgans Falls in 1998 and 1999 there is less than a 10% chance that returns of wild small and large salmon to Morgans Falls in year 2000 will be sufficient to meet conservation requirements. Returns of wild salmon to LaHave River above Morgans Falls have been consistently below replacement since 1986 (Figure 3). This trend does not bode well for the recovery of salmon stocks in SFA 20 and 21.

Hatchery smolts stocked in other low- or non-acidified rivers are expected to return to those rivers at rates similar to that observed at Morgans Falls. Stocking in these other rivers in 1999 was not as extensive as that above Morgans Falls.

River	Origin of stock	Number of smolts
La Have	LaHave	45,600
Mushamush	LaHave	9,500
Petite	LaHave	10,800
Musquodoboit	Musquodoboit	18,900

Partially-acidified rivers (pH 4.7 – 5.0)

Deteriorating water quality, declining wild salmon returns and low smolt-to-adult return rates indicate that wild salmon returns will be inadequate to meet conservation requirements in 2000. Declining survival rates of hatchery smolts stocked in Liscomb River suggest that hatchery returns in the year 2000 will provide insufficient augmentation to meet conservation levels in partially-acidified rivers receiving hatchery stocking.

River	Origin of stock	Number of smolts
Sackville	Sackville	20,500
Tusket	Tusket	45,400
Gold	Gold	16,400
Medway	Medway	41,600
Salmon (Digby)	Salmon (Digby)	7,000
Liscomb	Liscomb	56,000

Acid-impacted rivers (pH < 4.7)

The numbers of smolts stocked in four acid-impacted rivers in 1999 were similar to 1998. Returns in 2000 are expected to be similar to those of 1999.

River	Origin of stock	Number of smolts
Clyde	LaHave	11,500
Jordan	LaHave	4,900
Mersey	LaHave	9,900
East R. Sh. Hbr.	East River	22,000

Projections from ASRAM

Liscomb River

Projection of potential salmon populations in the Liscomb River were based on the ASRAM set-up in the Methods and data from 19 pH monitoring sites (Table 4).

The twenty-five-year projection was based on an initial egg deposition of 50,000 eggs (equivalent to the escapement of about 25 salmon of average age and size), the above chemistry, 10% maximum survival to the end of the first sea-winter, no intercept fisheries and 10% in-river mortality. Marine mortality for salmon was set at 20% in the second sea-winter and 30% in the third sea-winter.

The results indicated a population of only 11 grilse, 2 salmon and 1 repeat-spawning salmon after twenty-five years (Figure 6). The average pH driven mortality was 72% on egg to fry, 71% on parr and 17% on smolts. The river was capable of producing about 13 smolts per spawning fish. At low escapements the few smolts produced were large, about 19 cm, and survived at about 9%. The stock recruitment module estimated an initial value of 0.2 recruits per spawner. There was no calculable yield for the Liscomb River under these conditions and therefore the stock recruitment module was not run.

ASRAM was run in the Monte Carlo mode in order to assess the probability of extinction. A total of one hundred twenty-five year Monte Carlo simulations were run with uncertainty and trends in marine survival. Uncertainty in marine survival was set to 0.3 SD and trends in marine survival were set with 0.5 lag-1 auto-correlation. At 10% maximum survival there were no simulations that resulted in a population extirpation/extinction. However, the population never exceeded 50 fish in any simulation. At 5% maximum marine survival the population was extirpated/extinct three times.

LaHave River

Projection of salmon populations in the entire LaHave River were based on an ASRAM set-up with 65 pH sites (Table 5).

The twenty-five year projection was based on an initial egg deposition of 4,000,000 eggs (equivalent to the escapement of about 2,000 salmon of average age and size), pH data as in Table 4, 10% maximum marine survival to the end of the first sea-winter, no interception fisheries and 10% in-river mortality. Marine mortality was 20% in the second sea-winter and 30% in the third sea-winter.

The results indicated a population of 2,739 grilse, 648 maiden salmon and 481 repeat salmon after 25 years (Figure 7). The average pH-driven mortality was 19% on egg to fry 16% on parr and 2% on smolts. The river was producing about 17.5 smolts per spawning fish at equilibrium. Smolt lengths were about 15.9 cm for age-two smolts and 16.9 cm for the few three-year smolts produced. Early marine survival was therefore about 6% for two-year and 8% for three-year smolts. The stock recruitment module estimated an initial value for recruits per spawner of 1.8 (Figure 8). The egg deposition rate for maximum sustainable yield was 0.62 egg per m^2 or about 4,000,000 eggs, or about 2,000 spawners.

Projections from mean winter pH

Category	Number	%
Ext.	26	55
End.	14	30
Threat.	3	6
Sust.	4	9

Using the 1986 mean winter pH data and 10% marine survival, four rivers were sustainable (Table 6). These were Mushamush, Musquodoboit, St. Marys, and Country Harbour. Three rivers, LaHave, Ship Harbour and Smith, had a threatened status. Fourteen rivers were endangered and twenty-six were classified as extirpated/extinct.

Category	Number	%
Ext.	40	85
End.	6	13
Threat.	1	2
Sust.	0	0

Using the 1986 pH data and 5% marine mortality there were no rivers in the sustainable category (Table 7). Only the Musquodoboit River had a threatened status. Six rivers were classified as endangered including the LaHave, Mushamush, Ship Harbour, Smith, St. Marys, and Country Harbour. The remaining forty rivers were extirpated/extinct.

Management options – ARSAM projections

Harvest levels – LaHave River

The expected yield and percent of conservation failures for a fixed egg deposition management policy for the LaHave River was briefly examined. The ASRAM derived maximum sustainable yield point was used as the target egg deposition (4,016,216 eggs) and the conservation failure point was 2,000 fish, similar to the required escapement. A total of 10 trials of twenty-five-year simulations was run for each scenario. Random error for the marine survival function was set at 0.3 SD, lag-1 auto-correlation was set at 0.3 and error in escapement estimation was 0.2.

At 5% marine survival maximum, the model yielded (surplus in excess of the requirement) 12 fish per year and was below the conservation level 100% of the time (Figure 9). At 10% maximum marine survival the model for the LaHave River yielded an average of 1,130 fish per year, and was below the conservation point 82% of the time (Figure 10). None of the simulations resulted in a population extirpation/extinction.

Hatchery stocking –Liscomb River

Mitigation intervention projections were made for the Liscomb River only. Actions considered were parr stocking, smolt stocking and water treatment. The level of parr and smolt stocking was assumed to be equivalent to past programs where about 80,000 eggs were collected and a maximum of 60,000 parr or 39,600 smolts could be stocked. Hatchery smolts were discounted at a rate of five hatchery smolts to equal one wild smolt, similar to rates observed at Morgans Falls LaHave River (Amiro *et al*. 2000). Survival of hatchery parr was assumed to be equal to that of wild parr.

Broodstock removals were 40 grilse and 10 salmon to obtain 80,000 eggs. From a starting egg deposition of 50,000 eggs and 39,600 smolts stocked annually, the twenty-five year population was about 600 fish of which 70 fish were "wild". Hatchery smolt mortality was 5% for smolts stocked in the main river one week prior to migration.

Increasing the proportion of fish stocked as parr reduced the population to as low as 182 salmon if all hatchery products were stocked as parr.

pH alteration - Liscomb River

A raise of 0.2 pH units of the entire river was used to simulate a general pH recovery. The twenty-five-year projection reached a total of 154 spawners with a production of about 14 smolts per spawning fish. Recruit per spawner was 0.7 and therefore no sustainable yield was available.

A raise of 0.5 pH units for the entire river resulted in a population of 1,000 fish with production rate of about 17 smolts per spawning fish. Recruit per spawner was 1.6. Required escapement to achieve maximum sustainable yield was about 825 fish or an egg deposition rate of 0.502 eggs per m^2.

Raising the pH of the main river only by 0.5 units resulted in a population of 515 fish after 25 years. Recruit per spawner was 0.9 and therefore there was no sustainable yield.

Raising the main river by 0.5 pH units and annually stocking of 39,400 smolts resulted in a population of 2,678 fish of which 1,957 were 1SW recruits. Only 788 were of “wild” origin.

Validations

ASRAM projections

The count of wild salmon ascending the fishway on the Liscomb River declined from 1,000 wild salmon in 1990 to 9 fish in 1999. The 1999 count is consistent with the ASRAM projection for wild salmon under a scenario of 10% maximum marine survival.

The count of hatchery salmon is not consistent with ASRAM projections under either marine survival scenario. The count of hatchery fish declined from 460 in 1990 to 16 in 1999 despite similar numbers of smolts stocked annually.

Counts of adult salmon at Morgans Falls on the LaHave River (approximately 50% of the salmon production of the LaHave River) indicate an average count of 994 wild salmon 1990 to 1999. This level is about half that expected from the ASRAM projection. This result was not unexpected because of the low marine survival (2.04%) of wild smolts observed at Morgans Falls and the higher value of 10% maximum survival used in the projection.

Projections from mean winter pH

Projections based on mean winter pH and 10% marine survival suggested that 55% of the rivers on the Atlantic coast of Nova Scotia were already extirpated/extinct or were endangered of becoming extirpated/extinct (Table 6). At 5% marine survival that number increased to 85% of the rivers on the Atlantic Coast of Nova Scotia (Table 7). Seven rivers were projected to retain a population of wild Atlantic salmon, six of which were endangered.

The Liscomb was classified as *extirpated/extinct* even at 10% survival. This projection agrees with the ASRAM projection and with the observed wild adult salmon counts at the fishway.

The LaHave River was classified as *threatened* at 10% survival and was *endangered* at 5% survival. The surplus yield per spawner was 0.37 at 5% survival and 1.73 at 10% survival. These values are similar to the ASRAM projected stock recruitment initial value of 1.8 estimated with 10% maximum smolt survival.

The *extirpated/extinct* classification for the Tusket River at both 10% and 5% marine survival may be biased because of the contrast in river pH between the Carleton River branch and the Tusket River branch (LaCroix and Knox, 1998). The mean winter pH value of 4.58 does not allow production in the Tusket River branch. Water chemistry of the Tusket River system, counts at the fishway and downstream counts at the by-pass in 1999 indicate that production of wild salmon in the Carleton River branch may be excellent. The wild smolt count in 1999 indicated a production of 48 smolts per escaped spawning salmon in 1996 (Amiro *et al.* 2000).

The change of status for the East River Sheet Harbour from *endangered* at 10% marine survival to *extirpated*/*extinct* at 5% marine survival accurately reflects the general downturn in marine survival and the history of counts at the fishway since 1986. The count of wild salmon declined from 50 in 1987 to one salmon in 1998.

Juvenile salmon data

Juvenile salmon	Rivers	%
Present	15	32
Absent	13	28
Undetermined	19	40

A total of 27 rivers had electrofishing information available since 1986 (Table 8). Of the twenty-seven rivers electrofished, fifteen or 32% had juvenile Atlantic salmon present, thirteen or 28% were void of juvenile salmon. The current state of juvenile presence was undetermined in 19 rivers. Most of these "undetermined" rivers are known to have been extirpated/extinct of salmon based on low pH. For this reason they were assumed to be void of salmon when calculating agreement percentages.

When compared to the status categories estimated from mean pH (Table 6), at 10% marine survival, five rivers were classified as *extirpated/extinct* where Atlantic salmon parr were present, i.e., results were inconsistent with the electrofishing data. They were Tusket River, Middle River, Ingram River, Salmon River (L. Echo), and West River Sheet Harbour. When 5% marine survival (Table 7) was used the difference in agreement increased to 11 rivers.

Discussion

The data and analysis suggest that the status of Atlantic salmon populations in rivers of the Southern Upland is critical. The reduction in productive capacity attributed to acidification of the rivers has increased the vulnerability of the salmon populations to low and especially prolonged low marine survival episodes. The analysis indicates that reduction in marine survival from 10% to 5% increased the number of potential extirpations/extinctions from 55% of the rivers to 85% of the rivers.

Conditions that reduce a population's ability to withstand periodic low survival incidences increase the vulnerability of the population to extinction/extirpation. Loss in productive capacity is one factor that can increase vulnerability. Analysis has shown that productivity, measured as smolts per spawner or surplus yield, declined with increasing acidification (Korman *et al.* 1994). Population reduction thresholds may be considered as values of population parameters that result in population contractions. One such threshold may be calculated as the inverse of the productivity of a river and marine survival. In terms of smolts per spawner population reduction thresholds could be written as $1/S_{urv}$ where S_{urv} = smolt to spawning recruit survival. When this measure of productivity is plotted against survival, the loci of thresholds provide reference points to assess population stability expectations (Figure 11). If the value for production or survival is below the loci of points then recruitment will be less than the parental population and the population will likely decline. The presence of repeat-spawning fish and/or increased egg-to-smolt survival at low escapements (density-dependant survival) can buffer or delay population reductions.

The equilibrium productivity determined from ASRAM projections for the LaHave River was 17.5 smolts per spawning fish. The productivity observed for above Morgans Falls, 1996 to 1999, was 15.1 smolts per spawner and values ranged from 9.0 to 17.8. These data are close to the ASRAM projections and, considering the influence of highly variable returns and escapements of male hatchery grilse included in the escapement, the comparison provides strong evidence that the ASRAM projections are accurately calibrated. A productivity of 17.5 smolts per spawner requires 5.6% survival for stability and greater survival for a population increase. The measured smolt-to-recruit survival at Morgans Falls was 1.73% for the 1996-smolt class and 4.84% for the 1997-smolt class. Both of these values are below the population stability point for the LaHave River at moderate escapement levels. The Liscomb River productivity was 13 smolts per spawner without pH alteration, 14 smolts per spawner for a 0.2-pH unit improvement and 17 smolts per spawner for 0.5-pH unit improvement. Even at the higher recovery scenario, the Liscomb River would not have been above population replacement in these two smolt years (1996 and 1997).

This analysis indicates that persistence of salmon in the Southern Upland rivers is as dependent on the trend in marine survival for the coming years as much as it is dependent on pH conditions. For geo-chemical reasons, the majority of river productivity losses due to pH may have already taken place by 1986. The loss in productivity increased the stocks' vulnerability to low marine survival and marine survival has dropped considerably since 1986. Qualitative electrofishing, 1986 to 1999, while incomplete, indicated a high agreement in the incidence of extirpation/extinction with the mean pH model estimated at 10% marine survival. However, the same model estimated at 5% survival did not agree as well, indicating that populations may still persist. Nonetheless, the analysis indicates that, if marine survival continues at less than about 6%, more rivers will become extirpated/extinct and higher agreement can be expected with the lower survival scenario. This suggests that only seven rivers can be expected to support Atlantic salmon on the Southern Upland and because of low productivity all will be vulnerable to random events that can cause extirpation/extinction.

Options examined for management were instructive, if not encouraging. The LaHave River stock and recruitment analysis indicated that river-specific conservation requirements may provide opportunity for some harvest fisheries, albeit at very low yields. The MSY spawning escapement for the LaHave River of 4,016,216 eggs was close to the operational target, 1,960,000 eggs, for above Morgans Falls which is about 50% of the LaHave River. This target is equivalent to 0.62 eggs per m^2. Using this method, establishment of minimum acceptable population sizes and risk acceptance levels would allow river specific management protocols to be developed for the seven rivers expected to maintain Atlantic salmon populations on the Atlantic coast of Nova Scotia.

In order to provide harvests, the first requirement is to bring these rivers to productivity levels that are above the replacement threshold. Increasing productivity through supportive rearing was an effective technique according to the ASRAM projection when applied to the Liscomb River but the record of fishway counts did not support the projection. This loss of recruitment may be based on either lower pH or lower marine survival for hatchery smolts relative to wild smolts, or both. The return of hatchery smolts stocked in the Liscomb River is substantially lower than concurrent returns from stocking of hatchery smolts to the LaHave River. The possibility of a site-specific effect rather than a hatchery rearing effect may be found in comparing the return rates for the two rearing facilities used for the Liscomb River stocks.

The ASRAM model estimated pH mortality of hatchery smolts stocked in the Liscomb River was only 5.9%. Post-smolt mortality due to brief exposure to low pH has been reported for rivers in Norway (Staurnes *et al.* 1996) and was considerably higher for even short exposures to pHs as high as 5.3. The high mortality may be attributed to free aluminum ions found in Norwegian rivers. Nonetheless, it is likely that this mortality is not sufficiently accounted for in the ASRAM (Version March 1996). Until this effect is resolved, the effective use of hatchery smolts to mitigate for low productivity caused by low pH is uncertain. Stocking hatchery parr directly to the Liscomb River was not as effective as smolt stocking and even parr stocked to upriver pH refuges would not provide recruits without being detoured around pH toxic zones during the smolt migration.

Acknowledgements

Dave Longard drafted the maps and summarized the historic electrofishing data. Dave Longard and Eric Jefferson organized and summarized the pH data received from Gilles Lacroix and Derek Knox in 1998. Carolyn Harvie extracted the repeat-spawning information for the LaHave River from the Salmon Counting Facilities Database. Josh Korman assisted with reprogramming of ASRAM to handle the larger chemistry files necessary for the LaHave River analysis. Dick Cutting and Karen Rutherford provided valuable editorial comment that improved the text.

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Table 1. List of the 65 rivers of the Southern Upland of Nova Scotia that historically may have sustained Atlantic salmon populations.

1	Nictaux	24	Martins*	47	West (Sh Hbr)*
2	Round Hill	25	Gold*	48	East (Sh Hbr)*
3	Bear	26	Middle*	49	Kirby*
4	Sissibo	27	East (Chester)*	50	Salmon (P.D.)*
5	Belliveau	28	Little East	51	Quoddy*
6	Boudreau	29	Ingram*	52	Moser*
7	Meteghan	30	Indian	53	Smith*
8	Salmon (Digby)*	31	East	54	Ecum Secum*
9	Annis	32	Nine Mile*	55	Liscomb*
10	Tusket*	33	Pennant	56	Gaspereau Bk*
11	Argyle	34	Sackville*	57	Gegogan*
12	Barrington*	35	Salmon (L Major)*	58	St Marys*
13	Clyde*	36	Salmon (L Echo)*	59	Indian Harbour Lakes
14	Roseway*	37	West Bk Porters*	60	Indian*
15	Jordan*	38	East Bk Porters*	61	Country Harbour*
16	East	39	Chezzetcook*	62	Issacs Harbour*
17	Sable*	40	Musquodoboit*	63	New Harbour*
18	Tidney	41	Salmon (Hfx)*	64	Larrys*
19	Mersey	42	Ship Harbour*	65	Cole Harbour*
20	Medway*	43	Tangier*		
21	Petite*	44	E Taylor Bay*		
22	Lahave*	45	W Taylor Bay*		
23	Mushamush*	46	Little West		

* One of the 47 rivers used in the impact analysis

Table 2. Area ($m^2 * 100$) by gradient intervals determined from orthophoto maps and photographs for 48 rivers of the Southern Upland of Nova Scotia.

	Gradient interval (%)											
River	0-.12	.121-.249	.25-.49	.5-.99	1-1.49	1.5-1.99	2-2.49	2.5-2.99	3-3.49	3.5-5.0	>5.0	Totals
Salmon (Digby)	2,070	5,170	2,228	196	66	40	20	1	3	3	0	9,797
Tusket	83,059	33,030	23,095	7,749	2,331	732	402	138	77	100	68	150,780
Barrington	3,878	2,150	1,658	942	217	27	5	0	0	0	0	8,877
Clyde	31,016	14,923	7,166	1,737	266	176	32	13	5	11	3	55,348
Roseway	10,824	11,274	5,978	3,111	997	318	210	130	34	94	42	33,012
Jordan	13,537	8,324	5,245	1,270	408	213	126	24	10	37	13	29,206
Sable	329	4,167	3,221	1,030	346	99	5	0	0	0	0	9,198
Medway	23,793	40,382	23,427	8,392	1,875	542	196	212	120	179	56	99,174
Petite	730	2,404	2,347	1,285	268	38	80	8	1	9	4	7,174
LaHave	13,899	25,551	17,566	13,956	2,134	917	353	212	121	235	101	75,046
Mushamush	440	161	1,093	725	226	45	12	11	16	13	1	2,743
Martins	0	1,778	4,859	1,184	121	155	38	97	23	40	40	8,334
Gold	1,447	8,676	6,586	4,035	592	280	80	36	51	119	59	21,962
Middle	0	1,713	3,692	5,482	564	128	290	125	82	83	130	12,290
East (Chester)	198	126	1,321	2,061	337	192	164	50	44	72	33	4,598
Ingram	253	273	1,182	2,912	715	186	25	11	33	73	39	5,701
Nine Mile	284	201	3,320	902	363	118	145	91	45	54	45	5,569
Sackville	287	2,376	2,138	1,133	429	194	51	83	60	11	11	6,772
Salmon (L. Major)	0	0	358	113	135	70	51	7	0	7	8	750
Salmon (L. Echo)	89	1,711	2,340	2,317	484	236	107	70	38	61	39	7,493
East Bk Porters	58	298	1,349	393	116	58	65	41	1	0	16	2,394
West Bk Porters	0	12	455	400	123	92	27	21	42	11	3	1,185
Chezzetcook	0	0	133	801	403	131	161	13	40	56	19	1,757
Musquodoboit	15,206	3,948	2,289	833	268	280	90	92	30	83	7	23,125
Salmon (Hfx.)	23	228	436	1,571	225	77	77	78	51	30	38	2,834
Ship Harbour	903	3,589	6,079	7,538	1,301	383	235	135	122	156	76	20,518
Tangier	3,556	4,381	10,192	2,849	913	386	135	129	37	119	19	22,717
E Taylor Bay	58	0	70	42	47	12	19	3	0	5	3	260
W Taylor Bay	0	0	117	949	180	0	19	2	15	5	11	1,300
East (Sh Hbr)	1,479	6,963	12,605	6,728	1,651	421	428	58	55	51	63	30,501
Little West	350	290	2,698	390	193	57	0	35	47	1	26	4,087
West (Sh Hbr)	380	4,726	8,191	4,294	1,377	274	293	290	142	66	47	20,079
Kirby	0	714	523	205	39	82	0	27	0	14	0	1,604
Salmon (P.D.)	1,357	1,352	2,837	1,816	403	103	32	19	11	24	0	7,954
Quoddy	0	1,348	4,298	851	119	119	18	58	26	12	0	6,849
Moser	62	4,866	7,688	1,483	475	506	160	7	0	20	2	15,270
Smith	0	402	255	284	85	28	0	0	0	0	0	1,055
Ecum Secum	2,231	1,833	3,340	1,968	180	150	99	49	0	45	0	9,894
Liscomb	12,362	9,480	5,508	5,092	1,705	358	164	175	29	47	42	34,960
Gaspereau Bk	3	1,301	821	456	114	104	21	0	0	2	4	2,826
St Marys	18,863	24,664	8,554	4,528	1,123	487	302	102	44	49	0	58,717
Gegogan	0	0	80	96	115	32	51	0	6	1	0	382
Indian	910	855	977	5,650	750	221	128	64	103	36	50	9,743
Country Harbour	187	1,108	829	1,050	176	32	30	16	24	1	4	3,457
Issacs Harbour	16	0	408	1,427	441	91	4	24	2	33	22	2,469
New Harbour	0	483	1,206	472	345	140	118	29	113	130	113	3,148
Larrys	222	28	417	379	729	240	164	167	57	117	112	2,632
Cole Harbour	1,244	602	124	602	115	27	0	0	2	3	11	2,730
Southern Upland total	245,603	237,861	201,299	113,679	26,585	9,597	5,232	2,953	1,762	2,318	1,380	848,271
%	29	28	24	13	3	1	1	0	0	0	0	100

Table 3. Classification of sixty-three rivers draining the Southern Upland of Nova Scotia into four categories based on mean annual pH (Watt 1987).

Mean pH			
< 4.7	4.7 - 5.0	5.1 - 5.4	> 5.4
Argyle	* Bear	Annis	Belliveau
Barrington	Cole Harbour	Chezzetcook	Boudreau
Broad	East (Chester)	Gaspereau Brook	Gegogan
Clyde	East (Sheet Harbour)	Gold	Country Harbour
Indian (Guysborough Co.)	East (St. Margarets)	Kirby	Ecum Secum
Jordan	* Indian (Halifax Co.)	LaHave	* Meteghan
Larrys	Ingram	Medway	Indian Harbour
Nine Mile	Isaacs Harbour	Moser	Mushamush
Patterson	Liscomb	New Harbour	Musquodoboit
Pennant	Little East	Round Hill	Petite
Roseway	Martins	Sackville	Quoddy
Sable	* Mersey	Salmon (Digby)	Ship Harbour
Tidney	Middle	Salmon (Jeddore)	St. Mary's
East (Shelburne Co.)	* Nictaux	Salmon (Dufferin)	
	Salmon (Lake Echo)	Taylor Bay Brook	
	Salmon (Lake Major)	Necum Teuch	
	* Sissiboo		
	Tangier		
	Tusket		
	West (Sheet Harbour)		

* In these rivers most of the salmon habitat is unavailable due to impassable dams or falls.

Table 4. Average pH for seven sampling dates at 37 sampling sites in the Liscomb River (G. LaCroix[1] pers. comm.) combined into nineteen sites according to river codes used in the ASRAM model.

				pH							
No. of sample sites	Site no.	River code	Stream name	Nov-96 week 24	Mar-97 week43	May-97 week 51	Jul-97 week 7	Sep-97 week 17	Oct-97 week 21	Nov-97 week 27	mean
9	1	ES155	Liscomb River	5.04	4.81	5.06	5.37	5.49	5.22	4.89	5.13
1	2	ES155F	Creighton Brook	4.31	4.49	4.44	5.65	4.49	5.76	4.71	4.84
3	3	ES155H	Little Liscomb River	4.52	4.76	4.88	5.18	4.78	5.22	4.63	
1	4	ES155H3	The Runaround Brook	4.47	4.58	4.79	5.26	4.45	5.25	4.62	4.77
2	5	ES155H5	Black Brook	4.55		4.40	5.87	4.50	5.20	5.00	
3	6	ES155H7	Hardwood Lake Brook	4.61	4.62	4.82	5.48	4.51	5.08	4.57	
1	7	ES155H10	Slate Brook	4.5	4.65	4.4	5.14	4.72	4.83	4.5	4.68
2	8	ES155H17A	Trout Lake Brook	4.64		5.10	5.62	4.42	4.95	4.91	
1	9	ES155H18	Metkiff Mill Brook	4.33		5.53	5.37	4.68	5.44	4.93	5.05
1	10	ES155I	Sinclair Brook	4.66	4.91	5.2	5.54	4.52	5.4	4.95	5.03
1	11	ES155J	Clam Lake Brook	4.83	4.96	5.31	5.83	4.69	5.86	5.06	5.22
2	12	ES155Q	West Lake Brook	4.72	4.95	5.12	5.63	5.24	4.83	4.58	
3	13	ES155U	Crooked Brook	4.79	5.00	5.15	5.50	5.50	5.08	4.88	
1	14	ES155U4	Calf Moose Lake	4.7	4.57	4.9	5.03	5.26	5.05	4.57	4.87
1	15	ES155W	Golden Fleece Brook	4.73	4.9	5.04	5.24	5.04	5.24	5.03	5.03
2	16	ES155X	Big Brook	5.33	4.99	5.39	5.43	5.65	5.39	5.18	
1	17	ES155Y	Jordan Brook	5.2		5.31	5.3	5.44	5.58	5.06	5.32
1	18	ES155BB1	Laura Lake outflow						4.69		4.69
1	19	ES155CC1	Bruin Lake outflow	5.17		4.49	4.81	4.33	5.01	5.06	4.81

[1] Dr. G. Lacroix, St. Andrews Biological Station, N.B., E5B 2L9.

Table 5. Average pH for seven sampling dates at 65 sampling sites in the LaHave River (G. LaCroix pers. comm.) combined into forty-eight sites according to river codes used in the ASRAM model. (Sites 1 to 17 above Morgans Falls were as reported by Korman *et al*. 1994.

				pH							
No. of sample sites	Site no.	River code	Stream name	Nov-96 week 24	Mar-97 week43	May-97 week 51	Jul-97 week 7	Sep-97 week 17	Oct-97 week 21	Nov-97 week 27	Mean
13	18	SS95	LaHave River	5.73	5.75	5.83	6.12	6.05	6.00	5.64	5.87
1	19	SS95K	Grouse Brook	5.02	5.14	6.18	4.67	4.44	4.38	4.61	4.92
1	20	SS95L	Heckmans Brook	6.13	6.26	5.17	6.22	6.46	6.07	5.71	6.00
1	21	SS95M	Cooks Brook	5.76	5.86	5.78	6.18	6.11	5.85	5.18	5.82
8	22	SS95N	West Branch LaHave R.	5.29	5.33	5.34	5.71	5.96	5.77	5.02	5.49
3	23	SS95N1	Zwicker Brook	6.24	5.92	5.86	6.19	6.22	6.19	5.69	6.05
1	24	SS95N10	Demones Run	5.5	5.3	5.49	5.66	5.75	5.7	5.59	5.57
2	25	SS95N10A	Ash Brook	5.03	5.09	5.10	5.32	5.78	5.48	5.00	5.26
3	26	SS95N10B1	Smith Brook	4.91	5.03	5.22	5.62	4.96	5.34	4.71	5.11
3	27	SS95N10B2	King Brook	5.13	5.18	5.12	5.76	5.59	5.68	5.00	5.35
1	28	SS95N1A	Luck Brook	5.41	5.4	5.22	6.05	6.25	6.2	4.98	5.64
1	29	SS95N1B	Unnamed	5.78	5.68	5.75				5.12	5.58
1	30	SS95N2	Little Wiles Lake Brook	5.71	5.31	5.84	5.37	5.65	5.6	4.65	5.45
1	31	SS95N3	Unnamed	4.89	4.95	5.07	5.53	5.59	5.56	4.56	5.16
1	32	SS95N4	Unnamed	5.48	5.15	5.49	5.77	5.99		5.12	5.50
1	33	SS95N5	Fire Brook	5.19	5.24	5.26	5.26	5.41	5.24	4.6	5.17
2	34	SS95N7	Harley Lake Mill Brook	5.27	5.19	5.19	5.36	5.48	5.43	5.09	5.29
1	35	SS95N7B1	Harley Lake Mill Brook	4.9	4.96	4.86	5.01	4.97		4.82	4.92
1	36	SS95N8	Rhodenizer Lake	5.13	5.2	5.26	5.5	5.69	5.52	4.86	5.31
1	37	SS95O	Silver Mill Brook	6.05	5.85	5.96	6.27	6.25	5.9	5.7	6.00
2	38	SS95P	Rhodenizer Brook	6.35	6.13	6.08	6.17	6.29	6.03	5.80	6.12
1	39	SS95P1	Feener Brook	6.43	6.15	6.08	6.37	6.48	6.21	6.07	6.26
5	40	SS95Q	North Branch LaHave R.	5.74	5.62	5.77	5.96	5.96	6.07	5.78	5.84
1	41	SS95Q1	MacKay's Brook	6.24	6.07	6.11		6.02	6.33	5.65	6.07
2	42	SS95Q2	Patten Brook	6.20	6.05	6.17	6.24	6.19	6.21	5.83	6.13
1	43	SS95Q2A	Biscuit Brook	6.4	6.25	6.17			6.3	6.14	6.25
1	44	SS95Q3B	Church Lake Brook	6.05	4.8	4.81	5.12	5.29	5.16	4.49	5.10
1	45	SS95Q3B2	Shingle Brook	4.64	4.82	4.82		5.1	4.93	4.47	4.80
1	46	SS95Q3B3	Cape Marsh Brook	4.88	4.91	5.02	5.27	5.31	5.02	4.59	5.00
1	47	SS95Q3C	William Ross Brook	6.31	5.95	5.98	5.9	5.99	6.3	6.12	6.08
3	48	SS95Q3C1A	Soloman Brook	5.86	5.80	5.84	5.98	5.43	5.84	5.54	5.76
2	49	SS95Q3C1B	Nelson Brook	5.13	5.00	5.24	5.22	5.33	5.44	5.25	5.23
1	50	SS95Q6A1	Unnamed	6.46		5.98		5.22		5.71	5.84
1	51	SS95Q6B	Pine Lake Brook	4.34		5.18				4.35	4.62
1	52	SS95Q6C	Forties River	5.15		5.51	5.82	5.21	5.79	5.1	5.43
1	53	SS95Q6C1	Harlow Brook	4.83	4.89	5.14	5.4	5.27	5.39	5.05	5.14
1	54	SS95Q6C3	Forties River	4.7		5.7	5.98	5.97	5.92	5.69	5.66
1	55	SS95Q6C4	Forties River	4.65		5.04	5.26	4.52	4.89	4.84	4.87
1	56	SS95Q6D1	Gully River	4.85	4.93	5.08	5.3	4.95	5.33	4.91	5.05
2	57	SS95Q6E	Sherbrooke River	5.39	5.51	5.65	6.07	5.61	5.91	5.11	5.61
1	58	SS95Q6E2A	McClintock Brook	5.38		5.45				5.57	5.47
5	59	SS95Q6E3	Lake Paul Brook	5.37	5.47	5.76	6.06	5.47	5.65	5.59	5.62
1	60	SS95Q6E4	Sand Brook	4.76		5.05	5.53	5.24	5.3	4.65	5.09
1	61	SS95Q6E5	Sherbrooke River	5.8	5.18	5.66	5.95	6.59	6.11	6.02	5.90
1	62	SS95Q6E5B	Unnamed	5.07		5.49	5.73	5.75	6.05	5.69	5.63
3	63	SS95Q6F	Butler Lake Brook	6.16	5.90	5.90	6.00	5.90	5.06	5.78	5.81
1	64	SS95R	Ross Brook	6.48	6.27	6.36	6.37	6.33	6.23	5.91	6.28
2	65	SS95S	Indian Brook	5.86	5.89	5.90	6.23	5.61	5.94	4.99	5.78

Table 6. Area, optimum total parr at model (7.7), required egg deposition, pH and estimates of smolts, and yields to Canadian fisheries for 47 rivers in the Southern Upland of Nova Scotia as of 1986 estimated at 10% marine survival.

River	Area 100 m^2 units	Optimum Total parr	Required egg deposition 81% 1+parr & 1985 surv.	Oct-April pH 1986	% Survival Egg to Age-1+	Smolts at 75.6% 2yr	Egg to smolt survival %	Fish to Canada at survival 0.10	Surplus yield	Surplus yield $Spawner^{-1}$	Status
Salmon (Digby)	9,797	70,408	2,333,394	5.03	2.44	11,463	0.49	1,146	32	0.03	End.
Tusket	150,780	810,339	0	4.58	(0.02)	0	0.00	0	0	0.00	Ext.
Barrington	8,877	58,588	0	4.39	(1.06)	0	0.00	0	0	0.00	Ext.
Clyde	55,348	264,367	0	4.35	(1.28)	0	0.00	0	0	0.00	Ext.
Roseway	33,012	247,266	0	4.34	(1.33)	0	0.00	0	0	0.00	Ext.
Jordan	29,206	184,220	0	4.41	(0.95)	0	0.00	0	0	0.00	Ext.
Sable	9,198	88,538	0	4.27	(1.71)	0	0.00	0	0	0.00	Ext.
Medway	99,174	779,752	16,108,113	5.30	3.92	126,951	0.00	12,695	5,003	0.65	End.
Petite	7,174	74,278	1,397,922	5.37	4.30	12,093	0.87	1,209	542	0.81	End.
Lahave	75,046	697,185	8,698,838	5.77	6.49	113,509	1.30	11,351	7,197	1.73	Threat.
Mushamush	2,743	28,986	268,801	6.18	8.73	4,719	1.76	472	344	2.68	Sust.
Martins	8,334	102,046	22,614,845	4.65	0.37	16,614	0.07	1,661	(9,138)	(0.85)	Ext.
Gold	21,962	217,402	6,896,245	5.05	2.55	35,395	0.51	3,540	246	0.07	End.
Middle	12,290	159,281	10,398,776	4.81	1.24	25,933	0.25	2,593	(2,373)	(0.48)	Ext.
East (Chester)	4,598	61,037	11,765,819	4.66	0.42	9,937	0.08	994	(4,625)	(0.82)	Ext.
Ingram	5,701	75,173	3,628,084	4.89	1.68	12,239	0.34	1,224	(509)	(0.29)	Ext.
Nine Mile	5,569	72,013	28,962,527	4.62	0.20	11,724	0.04	1,172	(12,659)	(0.92)	Ext.
Sackville	6,772	75,927	3,664,474	4.89	1.68	12,362	0.34	1,236	(514)	(0.29)	Ext.
Salmon (L Major)	750	9,726	415,269	4.93	1.90	1,583	0.38	158	(40)	(0.20)	Ext.
Salmon (L Echo)	7,493	91,525	0	4.52	0.00	0	0.00	0	0	0.00	Ext.
East Bk Porters	2,394	28,602	2,538,917	4.75	0.91	4,657	0.18	466	(747)	(0.62)	Ext.
West Bk Porters	1,185	15,901	1,411,486	4.75	0.91	2,589	0.18	259	(415)	(0.62)	Ext.
Chezzetcook	1,757	24,661	836,001	5.02	2.39	4,015	0.48	402	2	0.01	End.
Musquodoboit	23,125	89,199	696,357	6.48	10.38	14,522	2.09	1,452	1,120	3.37	Sust.
Salmon (Hfx)	2,834	39,161	1,297,836	5.03	2.44	6,376	0.49	638	18	0.03	End.
Ship Harbour	20,518	248,054	3,838,965	5.54	5.23	40,386	1.05	4,039	2,205	1.20	Threat.
Tangier	22,717	236,650	16,162,437	4.80	1.19	38,529	0.24	3,853	(3,866)	(0.50)	Ext.
E Taylor Bay	260	2,996	577,525	4.66	0.42	488	0.08	49	(227)	(0.82)	Ext.
W Taylor Bay	1,300	18,971	3,656,951	4.66	0.42	3,089	0.08	309	(1,438)	(0.82)	Ext.
West (Sh Hbr)	20,079	233,711	10,274,963	4.92	1.84	38,050	0.37	3,805	(1,102)	(0.22)	Ext.
East (Sh Hbr)	30,501	352,661	10,727,230	5.07	2.66	57,417	0.54	5,742	619	0.12	End.
Kirby	1,604	17,789	448,895	5.17	3.21	2,896	0.65	290	75	0.35	End.
Salmon (P.D.)	7,954	87,481	2,285,425	5.15	3.10	14,243	0.62	1,424	333	0.30	End.
Quoddy	6,849	82,762	1,430,341	5.44	4.69	13,474	0.94	1,347	664	0.97	End.
Moser	15,270	181,659	6,020,367	5.03	2.44	29,576	0.49	2,958	83	0.03	End.
Smith	1,055	12,480	161,145	5.73	6.27	2,032	1.26	203	126	1.64	Threat.
Ecum Secum	9,894	100,755	1,741,306	5.44	4.69	16,404	0.94	1,640	809	0.97	End.
Liscomb	34,960	250,454	15,660,625	4.82	1.30	40,776	0.26	4,078	(3,401)	(0.45)	Ext.
Gaspereau Bk	2,826	32,360	1,026,497	5.05	2.55	5,269	0.51	527	37	0.07	End.
Gegogan	382	5,382	140,604	5.15	3.10	876	0.62	88	20	0.30	End.
St Marys	58,717	408,241	4,327,870	5.98	7.64	66,466	1.54	6,647	4,580	2.22	Sust.
Indian	9,743	123,900	39,187,427	4.63	0.26	20,172	0.05	2,017	(16,697)	(0.89)	Ext.
Country Harbour	3,457	38,307	427,528	5.91	7.26	6,237	1.46	624	420	2.05	Sust.
Issacs Harbour	2,469	35,351	2,210,461	4.82	1.30	5,755	0.26	576	(480)	(0.45)	Ext.
New Harbour	3,148	39,338	2,268,208	4.84	1.40	6,405	0.28	640	(443)	(0.41)	Ext.
Larrys	2,632	31,872	17,598,037	4.61	0.15	5,189	0.03	519	(7,885)	(0.94)	Ext.
Cole Harbour	2,730	16,148	0	4.54	0.00	0	0.00	0	0	0.00	Ext.

Table 7. Area, optimum total parr at model (7.7), required egg deposition, pH and estimates of smolts, and yields to Canadian fisheries for 47 rivers in the Southern Upland of Nova Scotia as of 1986 estimated at 5% marine survival.

River	Area 100 m^2 units	Optimum Total parr	Required egg deposition 81% 1+parr & 1985 surv.	Oct-April pH 1986	% Survival Egg to Age-1+	Smolts at 75.6% 2yr	Egg to smolt survival %	Fish to Canada at survival 0.05	Surplus yield	Surplus yield $Spawner^{-1}$	Status
Salmon (Digby)	9,797	70,408	2,333,394	5.03	2.44	11,463	0.49	573	(541)	(0.49)	Ext.
Tusket	150,780	810,339	0	4.58	(0.02)	0	0.00	0	0	0.00	Ext.
Barrington	8,877	58,588	0	4.39	(1.06)	0	0.00	0	0	0.00	Ext.
Clyde	55,348	264,367	0	4.35	(1.28)	0	0.00	0	0	0.00	Ext.
Roseway	33,012	247,266	0	4.34	(1.33)	0	0.00	0	0	0.00	Ext.
Jordan	29,206	184,220	0	4.41	(0.95)	0	0.00	0	0	0.00	Ext.
Sable	9,198	88,538	0	4.27	(1.71)	0	0.00	0	0	0.00	Ext.
Medway	99,174	779,752	16,108,113	5.30	3.92	126,951	0.00	6,348	(1,345)	(0.17)	Ext.
Petite	7,174	74,278	1,397,922	5.37	4.30	12,093	0.87	605	(63)	(0.09)	Ext.
Lahave	75,046	697,185	8,698,838	5.77	6.49	113,509	1.30	5,675	1,521	0.37	End.
Mushamush	2,743	28,986	268,801	6.18	8.73	4,719	1.76	236	108	0.84	End.
Martins	8,334	102,046	22,614,845	4.65	0.37	16,614	0.07	831	(9,969)	(0.92)	Ext.
Gold	21,962	217,402	6,896,245	5.05	2.55	35,395	0.51	1,770	(1,524)	(0.46)	Ext.
Middle	12,290	159,281	10,398,776	4.81	1.24	25,933	0.25	1,297	(3,669)	(0.74)	Ext.
East (Chester)	4,598	61,037	11,765,819	4.66	0.42	9,937	0.08	497	(5,122)	(0.91)	Ext.
Ingram	5,701	75,173	3,628,084	4.89	1.68	12,239	0.34	612	(1,121)	(0.65)	Ext.
Nine Mile	5,569	72,013	28,962,527	4.62	0.20	11,724	0.04	586	(13,245)	(0.96)	Ext.
Sackville	6,772	75,927	3,664,474	4.89	1.68	12,362	0.34	618	(1,132)	(0.65)	Ext.
Salmon (L Major)	750	9,726	415,269	4.93	1.90	1,583	0.38	79	(119)	(0.60)	Ext.
Salmon (L Echo)	7,493	91,525	0	4.52	0.00	0	0.00	0	0	0.00	Ext.
East Bk Porters	2,394	28,602	2,538,917	4.75	0.91	4,657	0.18	233	(980)	(0.81)	Ext.
West Bk Porters	1,185	15,901	1,411,486	4.75	0.91	2,589	0.18	129	(545)	(0.81)	Ext.
Chezzetcook	1,757	24,661	836,001	5.02	2.39	4,015	0.48	201	(198)	(0.50)	Ext.
Musquodoboit	23,125	89,199	696,357	6.48	10.38	14,522	2.09	726	394	1.18	Threat.
Salmon (Hfx)	2,834	39,161	1,297,836	5.03	2.44	6,376	0.49	319	(301)	(0.49)	Ext.
Ship Harbour	20,518	248,054	3,838,965	5.54	5.23	40,386	1.05	2,019	186	0.10	End.
Tangier	22,717	236,650	16,162,437	4.80	1.19	38,529	0.24	1,926	(5,792)	(0.75)	Ext.
E Taylor Bay	260	2,996	577,525	4.66	0.42	488	0.08	24	(251)	(0.91)	Ext.
W Taylor Bay	1,300	18,971	3,656,951	4.66	0.42	3,089	0.08	154	(1,592)	(0.91)	Ext.
West (Sh Hbr)	20,079	233,711	10,274,963	4.92	1.84	38,050	0.37	1,903	(3,004)	(0.61)	Ext.
East (Sh Hbr)	30,501	352,661	10,727,230	5.07	2.66	57,417	0.54	2,871	(2,252)	(0.44)	Ext.
Kirby	1,604	17,789	448,895	5.17	3.21	2,896	0.65	145	(70)	(0.32)	Ext.
Salmon (P.D.)	7,954	87,481	2,285,425	5.15	3.10	14,243	0.62	712	(379)	(0.35)	Ext.
Quoddy	6,849	82,762	1,430,341	5.44	4.69	13,474	0.94	674	(9)	(0.01)	Ext.
Moser	15,270	181,659	6,020,367	5.03	2.44	29,576	0.49	1,479	(1,396)	(0.49)	Ext.
Smith	1,055	12,480	161,145	5.73	6.27	2,032	1.26	102	25	0.32	End.
Ecum Secum	9,894	100,755	1,741,306	5.44	4.69	16,404	0.94	820	(11)	(0.01)	Ext.
Liscomb	34,960	250,454	15,660,625	4.82	1.30	40,776	0.26	2,039	(5,440)	(0.73)	Ext.
Gaspereau Bk	2,826	32,360	1,026,497	5.05	2.55	5,269	0.51	263	(227)	(0.46)	Ext.
Gegogan	382	5,382	140,604	5.15	3.10	876	0.62	44	(23)	(0.35)	Ext.
St Marys	58,717	408,241	4,327,870	5.98	7.64	66,466	1.54	3,323	1,256	0.61	End.
Indian	9,743	123,900	39,187,427	4.63	0.26	20,172	0.05	1,009	(17,706)	(0.95)	Ext.
Country Harbour	3,457	38,307	427,528	5.91	7.26	6,237	1.46	312	108	0.53	End.
Issacs Harbour	2,469	35,351	2,210,461	4.82	1.30	5,755	0.26	288	(768)	(0.73)	Ext.
New Harbour	3,148	39,338	2,268,208	4.84	1.40	6,405	0.28	320	(763)	(0.70)	Ext.
Larrys	2,632	31,872	17,598,037	4.61	0.15	5,189	0.03	259	(8,145)	(0.97)	Ext.
Cole Harbour	2,730	16,148	0	4.54	0.00	0	0.00	0	0	0.00	Ext.

Table 8. Summary of the presence of Atlantic salmon as determined by electrofishing in rivers of the Southern Uplands and Atlantic coast of mainland Nova Scotia, 1986 to 1999.

River	Sampling events	Pres/Abs.	Agreement with mean pH
Salmon (Digby)	1	Present	OK
Tusket	2	Present	Differs
Barrington	1	Absent	OK
Clyde	0	Undetermined	OK
Roseway	5	Absent	OK
Jordan	1	Absent	OK
Sable	0	Undetermined	OK
Medway	0	Undetermined	OK
Petite	4	Present	OK
Lahave	11	Present	OK
Mushamush	0	Undetermined	OK
Martins	0	Undetermined	OK
Gold	2	Present	OK
Middle	7	Present	Differs
East (Chester)	9	Absent	OK
Ingram	9	Present	Differs
Nine Mile	0	Undetermined	OK
Sackville	0	Undetermined	OK
Salmon (L Major)	0	Undetermined	OK
Salmon (L Echo)	10	Present	Differs
East Bk Porters	0	Undetermined	OK
West Bk Porters	0	Undetermined	OK
Chezzetcook	0	Undetermined	OK
Musquodoboit	8	Present	OK
Salmon (Hfx)	0	Undetermined	OK
Ship Harbour	0	Undetermined	OK
Tangier	1	Absent	OK
E Taylor Bay	0	Undetermined	OK
W Taylor Bay	0	Undetermined	OK
West (Sh Hbr)	1	Absent	Differs
East (Sh Hbr)	2	Present	OK
Kirby	6	Present	OK
Salmon (P.D.)	1	Present	OK
Quoddy	0	Undetermined	OK
Moser	1	Absent	OK
Smith	0	Undetermined	OK
Ecum Secum	2	Present	OK
Liscomb	2	Absent	OK
Gaspereau Bk	1	Absent	OK
Gegogan	10	Present	OK
St Marys	1	Absent	OK
Indian	0	Undetermined	OK
Country Harbour	1	Present	OK
Issacs Harbour	1	Absent	OK
New Harbour	1	Absent	OK
Larrys	1	Absent	OK
Cole Harbour	0	Undetermined	OK

Summary

State	Number	%
Present	15	32
Absent	13	28
Undetermined	19	40

Agreement	Number	%
OK's	42	89
Differences	5	11

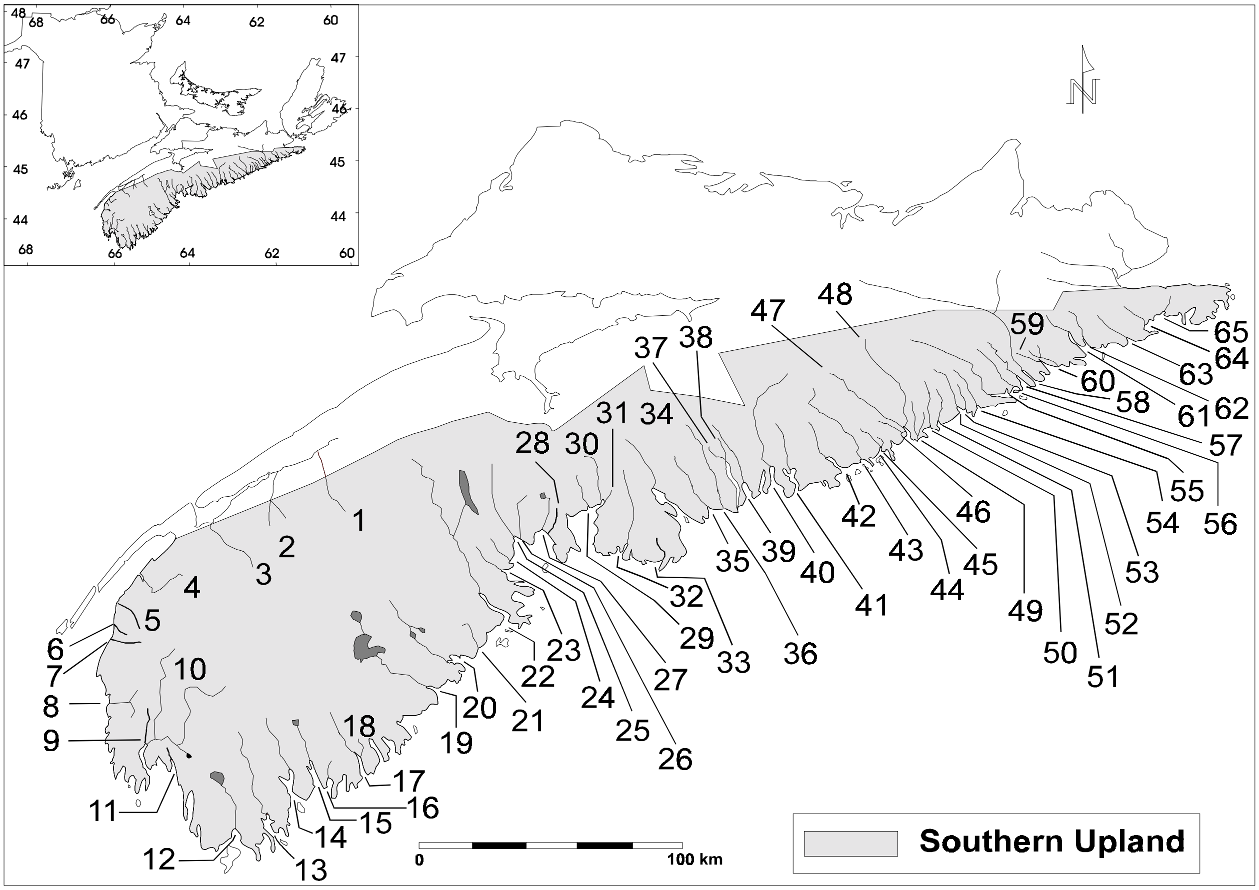

Figure 1. Map of the Southern Upland area (shaded) of Nova Scotia showing the locations of sixty-five rivers.

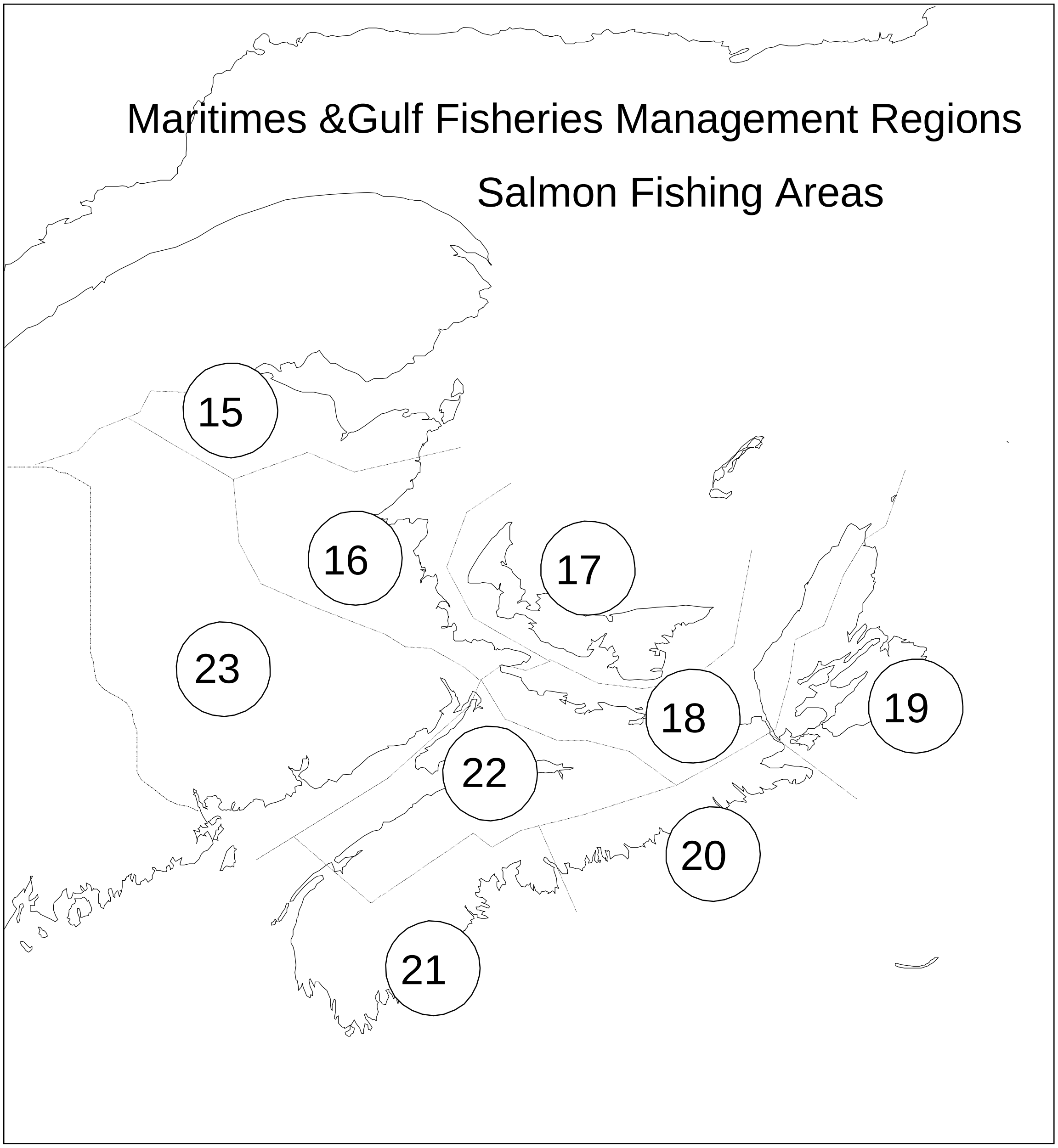

Figure 2. Atlantic Salmon Fishing Areas of the Maritimes, Canada.

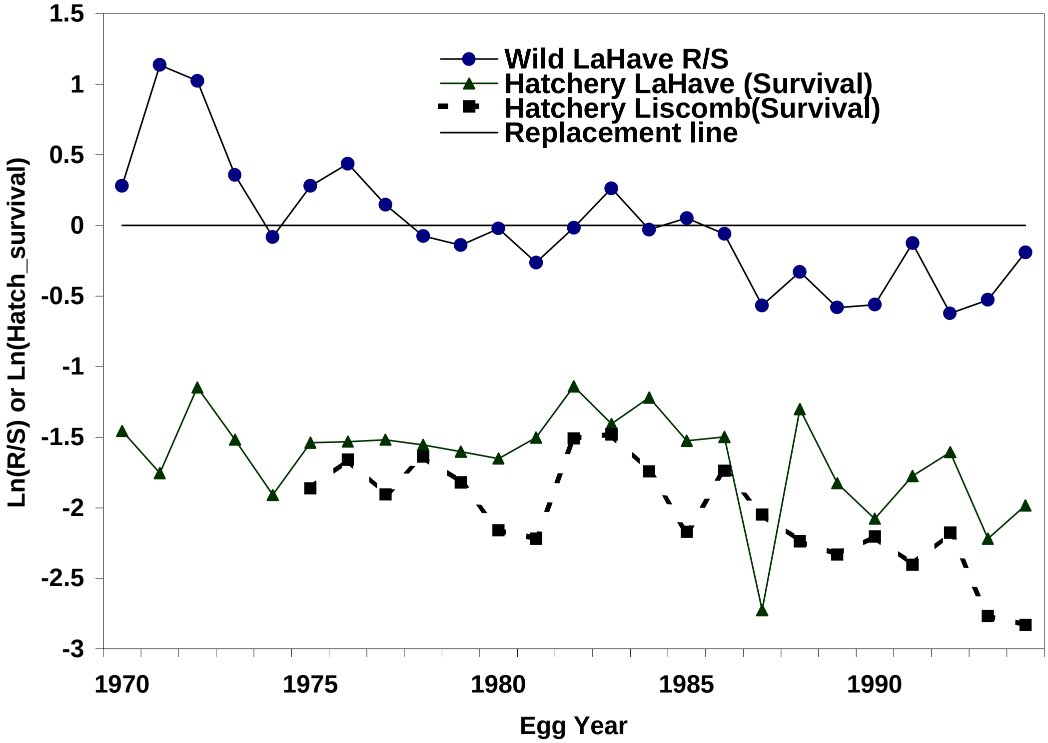

Figure 3. Plot of natural log (Ln) of Recruits/Spawner (R/S) for wild Atlantic salmon above Morgans Falls, 1970 to 1994, Ln(proportion survival) of hatchery smolts stocked above Morgans Falls on the LaHave River and hatchery smolts stocked in the Liscomb River, 1975 to 1994.

Return rates and smolt counts at Morgans Falls

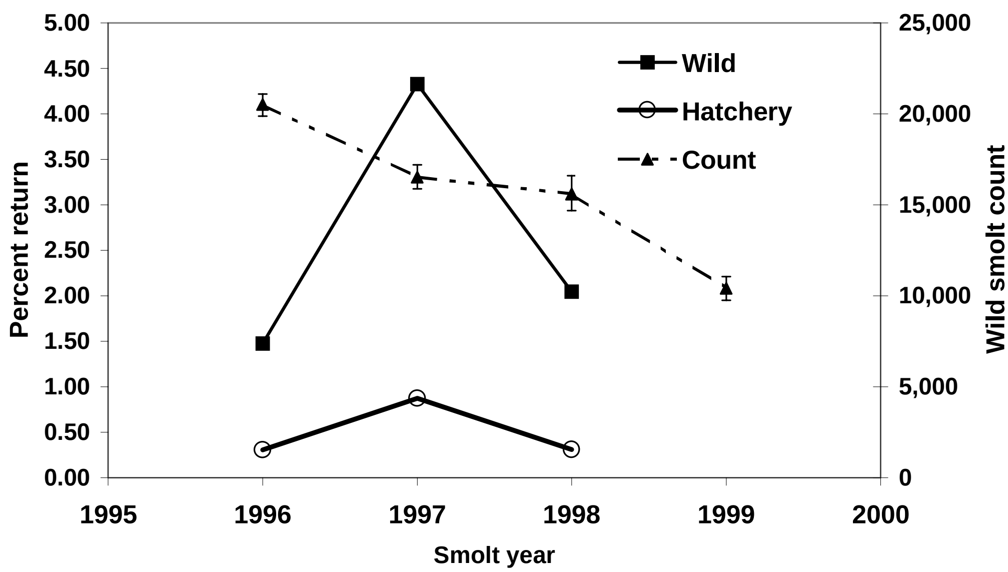

Figure 4. Modal, fifth, and ninety-fifth percentile estimates of wild smolts produced above Morgans Falls on the LaHave River, 1996 to 1999, plotted with return rate as one-sea-winter salmon and return rate of hatchery-stocked smolts as one-sea-winter salmon.

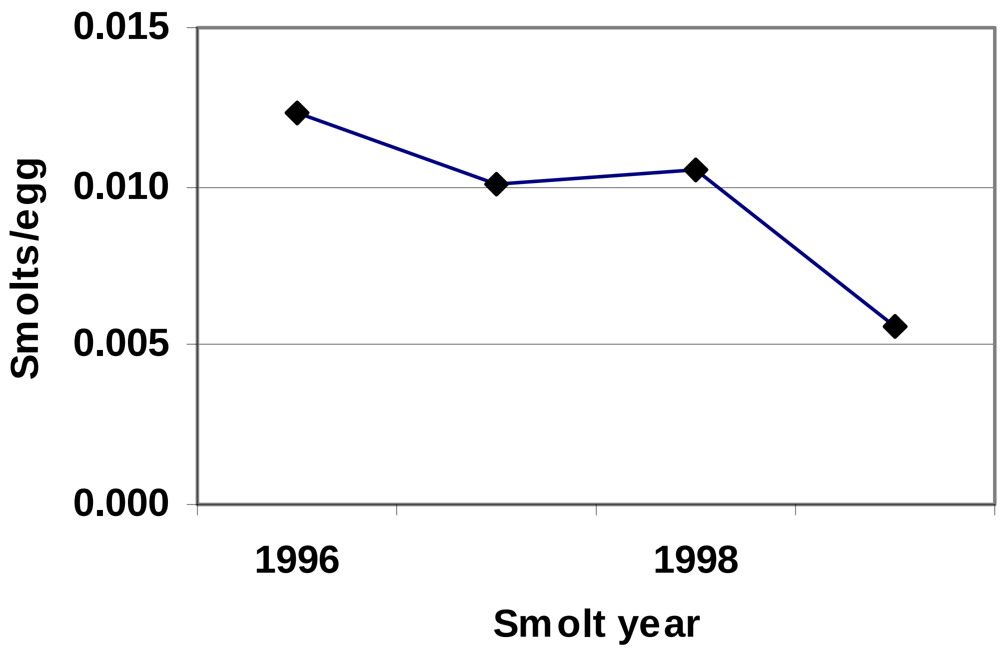

Figure 5. Number of wild smolts produced per egg deposited above Morgans Falls on the LaHave River 1996 to 1999.

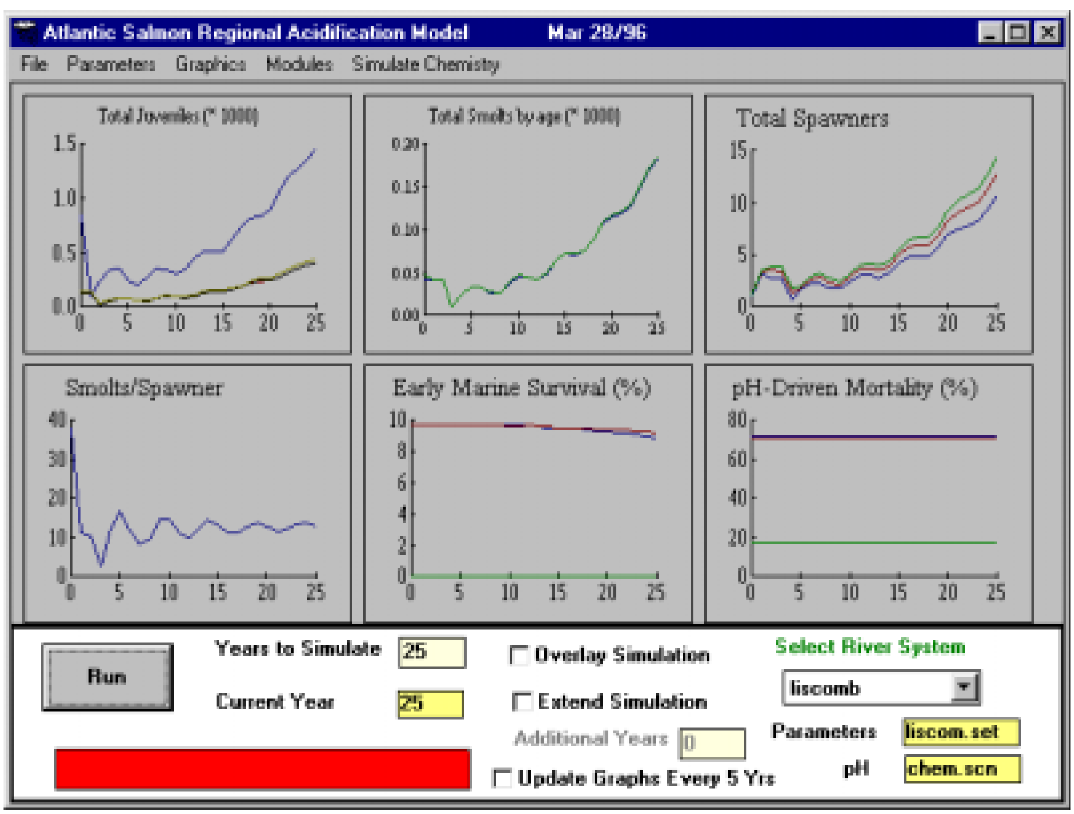

Figure 6. Results of ASRAM for Liscomb River without stocking.

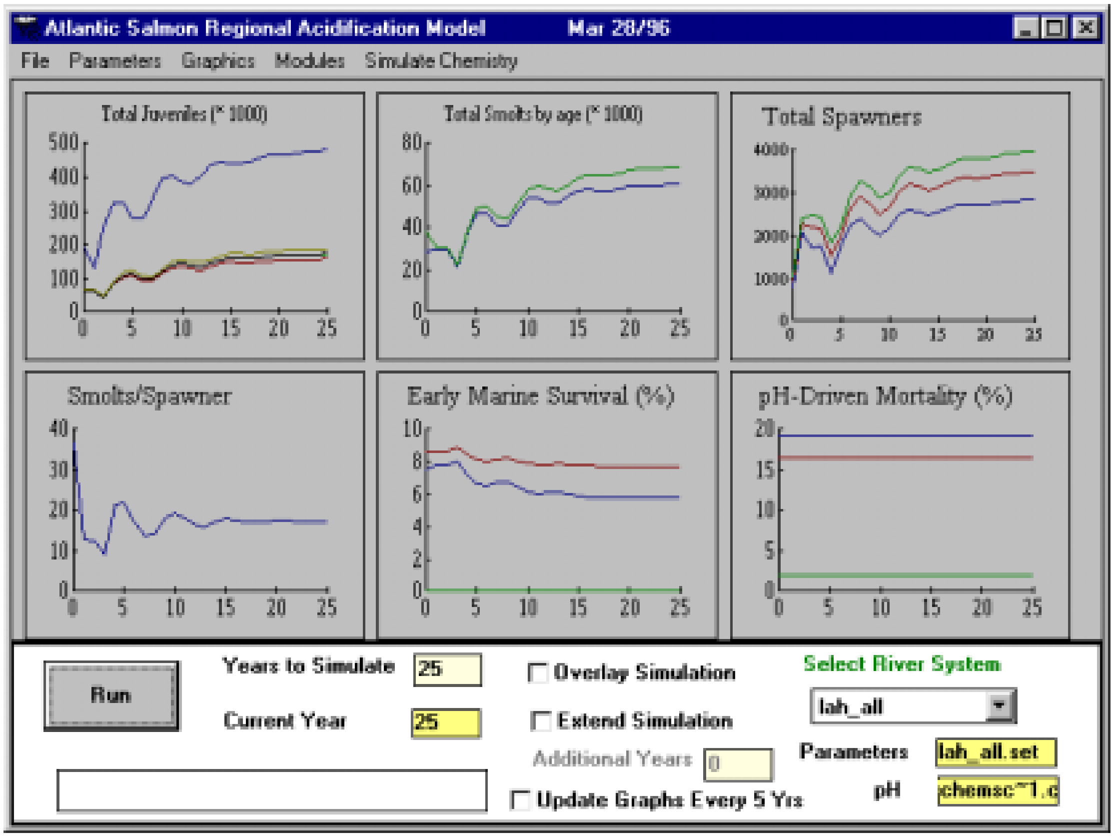

Figure 7. LaHave River ASRAM projection.

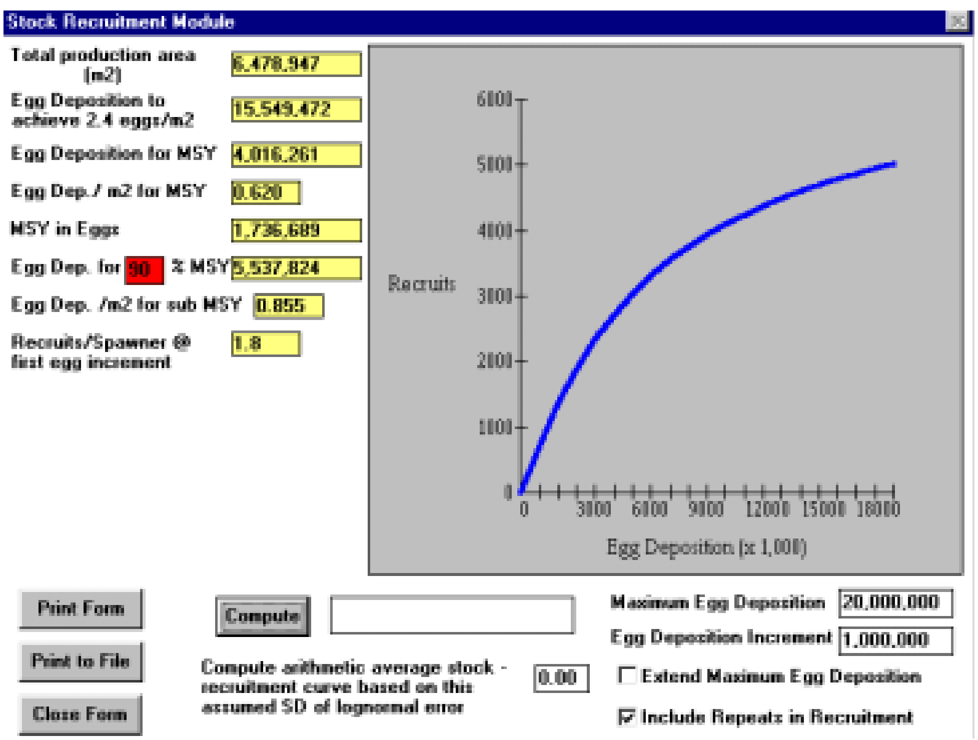

Figure 8. Stock and recruitment curve determined by ASRAM simulation for the LaHave River.

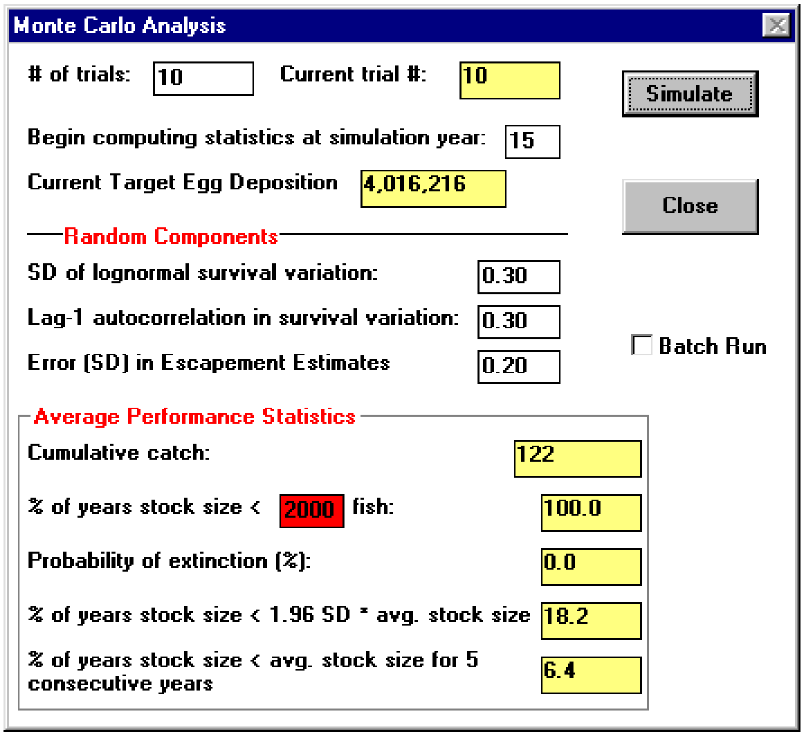

Figure 9. Output of harvest scenario for the LaHave River by ASRAM Monte Carlo module simulation at 5% maximum smolt survival.

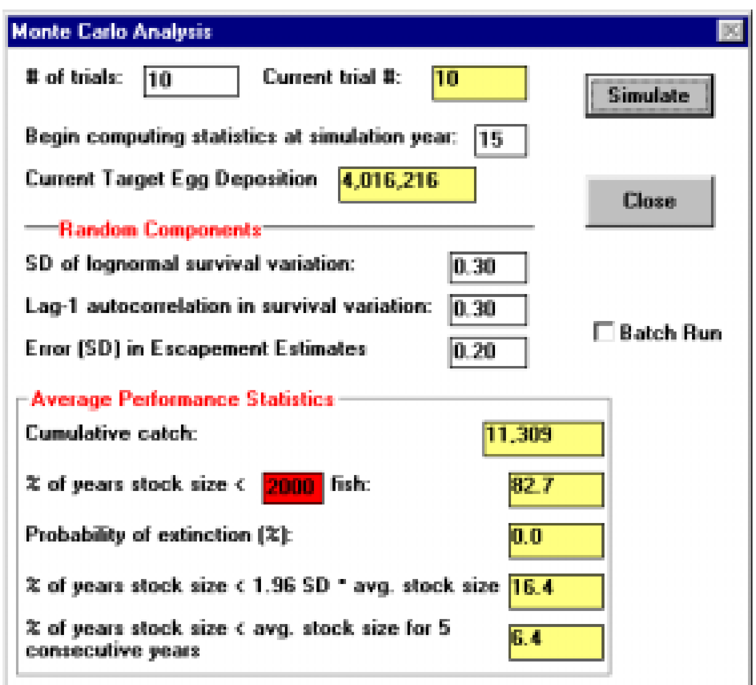

Figure 10. Output of harvest scenario for the LaHave River by ASRAM Monte Carlo module simulation at 10% maximum smolt survival.

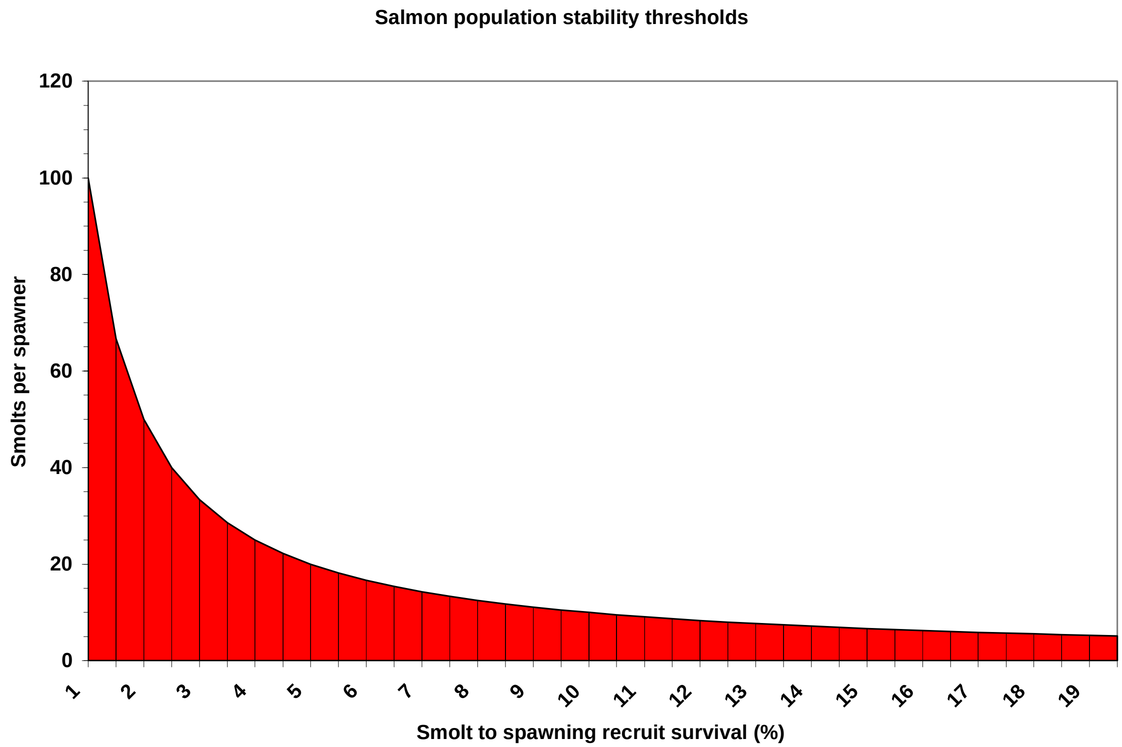

Figure 11. Loci of population stability thresholds in required numbers of smolts per spawning Atlantic salmon for smolt-to-adult return rates ranging from one to twenty percent.