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Summary of status and abundance trends for eastern Canadian Atlantic salmon (*Salmo salar*) populations

Sommaire des tendances relatives à l'état et à l'abondance des populations de saumon atlantique (*Salmo salar*) de l'est du Canada

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FOREWORD

This document is a product from a workshop that was not conducted under the Department of Fisheries and Oceans (DFO) Science Advisory Process coordinated by the Canadian Science Advisory Secretariat (CSAS). However, it is being documented in the CSAS Research Document series as it presents some key scientific information related to the advisory process. It is one of a number of contributions first tabled at a DFO-SARCEP (Species at Risk Committee / *Comité sur les espèces en péril*) sponsored workshop in Moncton (February 2006) to begin the development of a 'Conservation Status Report' (CSR) for Atlantic salmon. When completed in 2007, the CSR could form the basis for a Committee on the Status of Endangered Wildlife in Canada (COSEWIC) status report, recovery potential assessment and recovery strategy, and most importantly, enable DFO to implement pre-emptive management measures prior to engagement in any listing process.

AVANT-PROPOS

Le présent document est issu d'un atelier qui ne faisait pas partie du processus consultatif scientifique du ministère des Pêches et des Océans, coordonné par le Secrétariat canadien de consultation scientifique (SCCS). Cependant, il est intégré à la collection de documents de recherche du SCCS car il présente certains renseignements scientifiques clés, liés au processus consultatif. Il fait partie des nombreuses contributions présentées au départ lors d'un atelier parrainé par le MPO-SARCEP (*Species at Risk Committee* / Comité sur les espèces en péril) à Moncton (février 2006) en vue de commencer l'élaboration d'un rapport sur la situation de la conservation du saumon atlantique. Lorsqu'il sera terminé, en 2007, ce rapport pourrait servir de base à un rapport de situation du Comité sur la situation des espèces en péril au Canada (COSEPAC), à une évaluation du potentiel de rétablissement et à un programme de rétablissement mais, avant tout, il permettra au MPO de mettre en œuvre des mesures de gestion anticipées avant même de s'engager dans un processus d'inscription.

ABSTRACT

The status of Atlantic salmon populations throughout the Maritimes, Quebec and Newfoundland and Labrador is summarized by comparison of abundance to the river-specific conservation spawner requirements and by estimating abundance trends. Given the wide scope of the analyses and the inter-regional differences in data collection, life history and management, some assumptions had to be made to ensure comparability. The conclusions from some rivers are sensitive to underlying assumptions, such as the length of the time period over which a trend is calculated, but general patterns among regions did emerge. Salmon populations in SFAs 20 to 23 (Bay of Fundy and Nova Scotia mainland Atlantic coast rivers) show evidence of strong declines and are well below their conservation spawner requirement. In contrast, populations in Newfoundland and Labrador have typically been either increasing, or show little recent change in abundance. More variability exists in rivers throughout Quebec and Gulf of St. Lawrence Rivers in the Maritime Provinces. In these regions, some populations show declines but remain above or near their spawner requirement, other populations show increases, and others show declines.

RÉSUMÉ

Le présent sommaire de l’état des populations de saumon atlantique dans l’ensemble des Maritimes, du Québec et de Terre-Neuve-et-Labrador donne une comparaison de l’abondance et du nombre de géniteurs nécessaires pour assurer la conservation dans chaque cours d’eau ainsi qu’une estimation des tendances relatives à l’abondance. Compte tenu de la grande portée des analyses et des différences interrégionales dans la collecte de données, le cycle biologique et la gestion, nous avons dû formuler certaines hypothèses pour assurer la comparabilité. Les conclusions tirées sur certains cours d’eau sont sensibles aux hypothèses sous-jacentes, telles que la période en fonction de laquelle une tendance est calculée, mais des profils généraux sont ressortis entre les régions. Les populations de saumon dans les SPS 20 à 23 (cours d’eau de la côte de l’Atlantique de la partie continentale de la Nouvelle-Écosse et de la baie de Fundy) montrent des signes de déclin important et se situent bien en dessous du nombre de géniteurs nécessaires pour assurer la conservation. En revanche, le nombre d’individus chez les populations de Terre-Neuve-et-Labrador a augmenté de façon générale ou ont peu varié récemment. On constate une plus grande variabilité dans les cours d’eau du Québec et des provinces Maritimes se déversant dans le golfe du Saint-Laurent. Dans ces régions, certaines populations affichent des déclins, mais demeurent tout de même au-dessus ou près du nombre de géniteurs nécessaires pour assurer la conservation, tandis que d’autres affichent des augmentations ou des déclins.

Introduction

Atlantic salmon populations in eastern Canada vary markedly in both present status and recent trends. For example, salmon in the inner Bay of Fundy are presently designated “endangered” by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and have undergone declines of greater than 99% since the early 1970’s (Gibson and Amiro 2003, Gibson et al. 2003a, Gibson et al. 2003b). In contrast, abundances of monitored Atlantic salmon populations in many Newfoundland and Labrador rivers have been increasing and many are above their conservation requirements (O’Connell et al. 2005). Here, our objective is to provide an overview of the status of salmon populations regionally using similar criteria in all areas.

Status Relative to Conservation Requirements

Methods

The description of and sources for the abundance time series used in these analyses are provided in Appendix 1. In total, 131 series were considered, but 16 series were excluded as being unrepresentative of wild abundance in the region due to high rates of stocking or other enhancement or restoration activities. Not all of the remaining series were appropriate for all analyses, as abundance estimates were not available for all rivers in all years.

From the perspective of managing fisheries, Atlantic salmon populations in eastern Canada are typically assessed relative to a river-specific egg deposition requirement, known as the conservation spawner requirement (O’Connell et al. 1997, Chaput 2006). Within Nova Scotia, New Brunswick and Newfoundland and Labrador, this requirement is calculated on the basis of the amount of habitat within a watershed and an assumed egg density thought to optimize smolt production, (currently 1.90 eggs per square meter of fluvial habitat in Labrador (Reddin et al. 2006) and 2.40 eggs per square meter in the other regions, with a correction factor for lacustrine habitat in Newfoundland (Chaput 2006)). In Quebec, conservation requirements were redefined in 1999 to reflect the minimum egg deposition necessary to reach maximum spawning escapement on a river. Values are calculated based on the wetted area of a river scaled by a habitat suitability index and a target egg density of 1.68 eggs per square meter (Caron et al. 1999). Although reference points are defined as the number of eggs deposited by spawning salmon, the requirements are sometimes presented as the number of small and/or large salmon that would be needed to produce the required egg deposition on the basis of sex ratio, size-specific fecundity and the proportion of large and small salmon typically found in the rivers. The requirements are only approximate when presented as the number of fish because the number of salmon needed to produce the required number of eggs is expected to change as the above life history parameters change.

Results

The average size of wild salmon populations in the Maritime Provinces relative to their conservation requirement is shown in Figure 1 for a recent time period (2001-2005), a time period 1 decade or roughly 2 generations previous to now (assuming a 5 year generation time: 1991 to 1995) and one roughly 4 generations ago (1981 to 1985). Returns generally exceeded the conservation requirements in the early time period. Exceptions include rivers impacted by acidification (East

River at Sheet Harbour, Liscomb) and those impacted by dams (Saint John, St. Croix). Although salmon abundance in some rivers has increased slightly, the figure shows an overall decline in abundance from time period to time period. By the 1991 to 1995 period, none of the populations south of the North River were consistently larger than their conservation requirements, and only the Margaree and North River populations were consistently larger than the requirement by the 2001 to 2005 time period. Presently, all populations south of the St. Mary's River are at less than 10% of the requirement for both small and large salmon with the exception of the LaHave River population.

The data for Quebec salmon populations is shown in the same way as that from the Maritime Provinces in Figure 2. In Quebec, the conservation requirements are given for large salmon only. The returns relative to requirements were highly variable in the 1981 to 1985 time period. Populations north of the Mingan River show an overall declining trend through time such that by the 2001 to 2005 time period, only one of ten rivers had returns greater than 50% of the spawning requirement. Of 27 Quebec Rivers south of the Mingan, returns to 9 averaged greater than the conservation requirement in the 2001 to 2005 time period.

Patterns in Newfoundland and Labrador differ in that increasing trends are apparent for many populations (Figure 3). On average, returns in 5 of 8 populations exceeded their requirements for small salmon in the 1981 to 1985 time period, 8 of 13 populations exceeded their requirements in the 1991 to 1995 time period and returns in 7 of 12 populations exceeded their conservation requirements in the 2001 to 2005 time period. Within this region, some populations (e.g. the Exploits, Northwest and Terra-Nova) are not meeting conservation requirements. This may be partially due to the fact that these requirements include habitat above natural barriers, around which fish passage has been recently provided. The exploits and Terra Nova rivers have also been subject to enhancement activities. These populations are increasing in size.

Trends in Abundance

Methods

When assessing the status of wildlife in Canada, COSEWIC uses trends in abundance over 10 years or three generations (whichever is longer) as one of their criteria for determining the extent to which a species is at risk of extinction. The interpretation of a declining trend when designating status also depends on whether the causes of the declines are known and have ceased. For populations where the cause of the decline is known and has ceased, a decline greater than or equal to 70% corresponds with the "endangered" category, whereas a decline greater than 50% but less than 70% corresponds with the "threatened" category. If the cause of the decline is unknown, the categories "threatened" and "endangered" correspond with declines greater than or equal to 30% to 50% respectively. Where $N_{present}$ is the abundance now, and N_{past} is the abundance at some time in the past, percent decline is calculated as:

$$\% \text{ Decline} = (1-N_{present}/N_{past})*100.$$

It is important to note that COSEWIC does not assess species based solely on trends, but also includes other criteria, such as: population size, the number of populations, their range and area occupied.

Given the variability in life history traits among salmon populations (Hutchings and Jones 1998, O'Connell et al. 2006), generation time would be expected to be highly variable. The generation time of iBoF salmon was calculated as 3.65 years (Amiro 2003). Generation time would be longer with a higher proportion of two sea-winter returns, with older ages at smoltification, or with increased survival between spawning events. One method for estimating the generation time of a population is to add the reciprocal of the instantaneous rate of natural mortality to the age at 50% maturity. For a hypothetical population composed of equal proportions of age-2 and age-3 smolts, equal proportions of one sea-winter and two sea-winter maiden adults, and in which natural survival between consecutive repeat spawnings is 30%, the estimated generation time would be 5.2 years. In the analyses herein, we assumed a generation time of 5 years for all populations in order to have consistent time periods on which to compare trends.

We considered several methods to evaluate declines over the given time periods, including two models and four methods of fitting the models. One approach was to calculate the extent of the decline as the ratio of the population size in two time periods separated by 15 years (representing roughly 3 generations). In order to dampen the effect of year-to-year variability, we used the 5-year periods (missing values were dropped) when calculating the ratio. The five-year time period was chosen to represent approximately one generation. Although this method is easy to implement, a drawback is that confidence intervals for parameter estimates cannot easily be calculated. We therefore re-parameterised the model into the form:

$$N_t = \begin{pmatrix} N_1 & s_t = 1 \\ N_1 p & s_t = 2 \end{pmatrix},$$

where s is a state variable that indicates whether a year is in the first or second time period, and the two estimated parameters are N_1, the average abundance during the first time period and p, the change in abundance between the two time periods. This model, termed here the "ratio model", estimates the extent of decline and is not influenced by data between the time periods of interest.

A second approach to estimating declines was the use of a "log-linear model":

$$N_t = N_0 e^{zt}.$$

Here, N_0, the population size at the start of the time series, and z, the instantaneous rate of change in abundance, are the estimated parameters. The change in population size over the full time period, p, is given by e^{zt}. This model is easily fit using least squares after transformation to a log scale. Since it uses all data between the time periods the standard error of z increases when abundance changes markedly during the period. However, when log transformed, zero abundances are difficult to include (small values must be added). Additionally, if residuals are not appropriately distributed, depending on when and how abundance changes during the time period, some points can have either high leverage or little influence on the model fit.

Either of these models can be fit to an abundance time series using maximum likelihood after choosing an appropriate probability distribution for the error structure. Confidence intervals can then be found using likelihood ratios. We tested normal, Poisson and lognormal distributions, and found that although the point estimates for the decline are not very sensitive to the assumed error structure, the confidence intervals about the estimate varied among the distributions. The normal distribution gave confidence intervals that were unrealistically large, the result of the associated assumption that errors are independent of population size. At the other extreme, the Poisson distribution gave confidence intervals that were unrealistically small, a result of the assumption that the variance is known and is equal to the mean. When the Poisson model was fit using quasi-likelihood (involving the estimation of a dispersion parameter used to rescale the variance as a function of the mean), it produced confidence intervals intermediate in size that were similar to those produced when a lognormal error structure was used. We adopted the lognormal errors (estimated using likelihood ratios) for use in these analyses based in part on the above similarity, and in part on the implausibility of the intervals produced using the other distributions.

Results

Plots of the abundance (large and small salmon combined) time series in each river are shown for the Maritimes (Figure 4), Quebec (Figure 5), and Newfoundland and Labrador (Figure 6). The log-linear model fit and the 5-year mean population sizes are overlaid where sufficient data is available. Of the 60 cases where data series were sufficient to fit both models, the log-linear model produced higher estimates of the rate of decline than the ratio model in 39 cases, although fits were mostly similar (Figure 7). In some cases, (e.g. the Miramichi and Margaree in Figure 4) populations show recent increases that the log-linear models didn't capture, resulting in an overestimate of the extent of decline. Visual examination of the 3-generation trends in the longer abundance series indicates that in some cases, estimates can be sensitive to the selected time period used in the analysis (or number of generations). For example, the Margaree population increased in size in the mid-1980's, and if the analysis had been extended back to include a 4th generation, the population would have shown an increase in abundance (Figure 4). A contrasting example is the Conne River in Newfoundland, where there has been little change in abundance within the last two generations, yet the population shows strong evidence for a decline when the time period is extended to include a third generation (Figure 6).

Population trends for three time periods, estimated using the ratio model, are summarized in Figures 8 to 10. In the Maritime Provinces (Figure 8), the 5-year mean population size ending in 2005 is greater than the 5-year mean population size ending in 1987 in only three of the assessed rivers. All rivers south of Cape Breton show declines of greater than 75%. Some Gulf shore rivers show recent declines (West Antigonish to Buctouche), although there have been recent increases in the Miramichi and Restigouche populations (2000 to 2005 comparison).

Within Quebec (Figure 9), abundance in most populations north of Laval has declined by more than 50% since the 5-year period ending in 1987. Over the last generation (5-year time periods ending in 2000 to 2005), most of the northerly populations show declines whereas abundance has been more or less stable or increasing in populations to the south.

Of 10 populations in Newfoundland and Labrador (Figure 10), six populations show an increase in size between the 1987 and 2005 time periods. Over the last generation (5-year time periods ending in 2000 to 2005), 11 of the 24 populations for which data are available show an increase in population size. For most of the other populations, the declines are less than 30%.

Three-generation changes in population size for salmon in each region are shown in Figures 11 to 13. Within the Maritimes Provinces, 17 of 18 assessed populations in the Maritime Provinces show declines, although the decline in the Restigouche River is not significantly different from zero at a 95% confidence level. Declines are greater to the south, and all assessed Bay of Fundy and Nova Scotia mainland Atlantic Coast Rivers have declined by more than 75% during this time period, with many declines greater than 90%. Within Quebec (Figure 12), patterns vary regionally and trends range from declines of greater than 80% to doublings in population size. Generally, declines appear greater in more northerly populations. Of 13 populations with sufficient data in Newfoundland and Labrador (Figure 13), only 3 populations have shown a decline in the last 15 years.

These results are summarized in Figure 14. All assessed populations in SFA's 20 to 23 have declined by more than 80%. Nearly three quarters of the populations in SFA 19 have declined by 30% or more. Within SFA 18, some populations have declined by more than 50%, although uncertainty exists because the estimates are variable and sensitive to the time period used. Additionally, abundance series for these rivers are derived from the recreational catch which is influenced by more than just abundance. Within SFA 16, the single population shows a decline, but this population is near its conservation requirement and has shown increases during the last few years. The decline of the single population in SFA 16 is not significantly different from zero. Trends in populations in Quebec are variable with the largest declines in Q10. Although abundance in a few populations in Newfoundland and Labrador (SFA 4, 5, 9, 11, 13, 14) has declined; overall, populations in this region do not show evidence of declines in abundance over the last three generations.

Discussion

In this paper, we present an overview of the status of wild salmon using both population declines as well as abundance relative to the spawner requirements. Several caveats are attached to the results. First, data series used for both analyses are the number of adult salmon returning to each river annually. The status relative to the egg conservation requirement is typically assessed after removals by in-river fisheries. Because many fisheries in the Maritime Provinces are closed and others are limited to catch and release only, we selected returns prior to the removals by in-river fisheries as a more standard metric of population size across regions. Hence the interpretation of the results differs from the traditional comparison of the spawning escapement to the conservation requirement. Additionally, we focus only on the wild component of the populations: hatchery-origin fish are not included in the analysis, and comparisons are made on the basis of the number of fish, rather than the number of eggs, using the conversions as a basis for the comparison. Owing to these assumptions, the results may differ from those presented in other assessments. In rivers where harvest fisheries still exist, the number of spawners relative to the requirement would be over-estimated using the method herein, whereas in rivers in which fish are surviving longer and reaching a larger size (as a result of fisheries closures, say), the status relative to the conservation requirement would be underestimated using the above method.

Factors related to population monitoring may also have confounding influences on the assignment of status, whether one is assessing abundance relative to spawner requirements or is using trends.

For example, the methods used to estimate the number of salmon varies among rivers (Appendix 1). In some cases, estimates are counts of the number of salmon at counting fences or fish ladders, whereas in some other rivers they are extrapolated from the estimated recreational catch and in others are model-based. As such, the certainty with which status is assessed can be highly variable among rivers. Also, many rivers are either presently being stocked or have been stocked in the past. Although hatchery-origin fish are not included in this analysis, the progeny of hatchery-origin fish cannot be distinguished from progeny of wild-origin fish, and hence stocking may disguise long-term abundance trends (Myers et al. 2004). Recent stocking may reduce the estimate of the extent of decline in a population, whereas stocking near the start of the time series may lead to an overestimate of the extent of decline.

The analysis presented was limited to rivers for which abundance data were available spanning the relative time periods. As such, it does not completely summarize the state of knowledge. In Nova Scotia Rivers, some monitoring programs were curtailed as population sizes dwindled, while in Newfoundland, budget reductions have resulted in the termination of some past monitoring programs (e.g. Biscay Bay River, Northeast River Placentia, Humber River). An example is the Liscomb river in SFA 20, where salmon returns decreased from a high of 1,614 salmon in 1987 to just nine wild salmon in both 1998 and 1999 (Amiro et al. 2000), a result that is not included in the summaries (but is shown in Figure 4) due to the selection of dates. Additionally, other kinds of data are available other than abundance estimates that provide information about status. For example, at least 65 rivers within the geological area known as the Southern Upland of Nova Scotia (most of SFAs 20 and 21) were known to maintain salmon populations, of which four are included herein. Information about habitat in other rivers also provides information about status. In many rivers, acidification has either extirpated or is threatening populations. As of 1986, fourteen of the rivers in SFA 20 (including the St. Mary's River) and eight rivers in SFA 21 (including the LaHave River upstream of Morgan's Falls) were classified as low- or non-acidified (pH > 5.1). Twenty rivers were partially acidified (annual mean pH was between 4.7 and 5.0). At least fourteen rivers were classified as heavily acidified (pH < 4.7) and had lost their populations of Atlantic salmon (Amiro et al. 2000). Since that analysis, pH has not improved and populations have been further threatened by a decrease in marine survival to only 3%. Additionally, some populations are assessed using recreational catch data. The validity of this approach, however, is likely river-specific as O'Connell (2003) has shown that the use of angling data in the calculation of stock size and compliance with conservation requirements is potentially "quite risky". As population size decreases, or as fisheries are closed, this method of monitoring populations is lost and therefore these populations were not included in the analysis. All of the above scenarios would lead to an overly optimistic statement of status throughout regions. In contrast to the results presented here, WWF (2001) reported that salmon populations in eastern Canada declined by at least 75% from 1970 to 2000. While the results are not directly comparable due to the different time periods, the results herein are certainly more optimistic than those of WWF, possibly as a result of survey biases.

Causes of the declines in many salmon populations are not known, although high rates of exploitation in ocean fisheries, such as that experienced in past years at West Greenland, has been suggested as a potential cause for some populations. Recently, fisheries in the latter region have been curtailed, while most directed marine fisheries for salmon in the Northwest Atlantic have now been closed. Populations in some areas have increased in size co-temporally with the reduced catch while in other areas total stock size of some populations is no greater now than it was prior to large scale fishery closures (e.g. Dempson et al. 2004). If over-fishing was one of the primary causes of declines in some regions and has subsequently been curtailed, it would have implications for the viability of populations.

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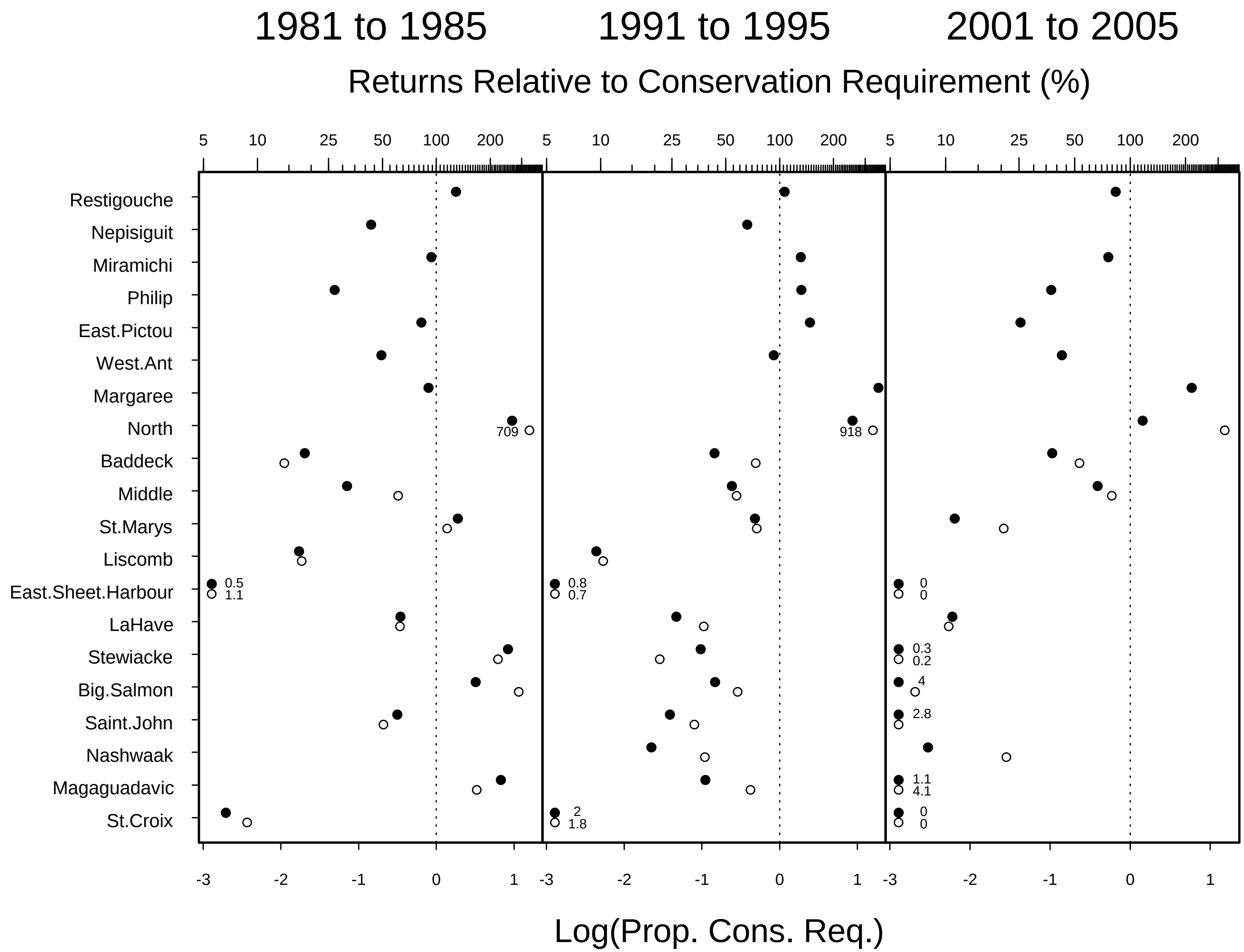

Figure 1. Five year mean numbers of large (dark points) and small (light points) salmon returning to rivers in the Maritime Provinces as a percentage of the conservation spawner requirement for the river. Three time periods are shown. Spawner requirements for both size categories are not used for all rivers. Points that are outside the range of the graph are labelled with their value.

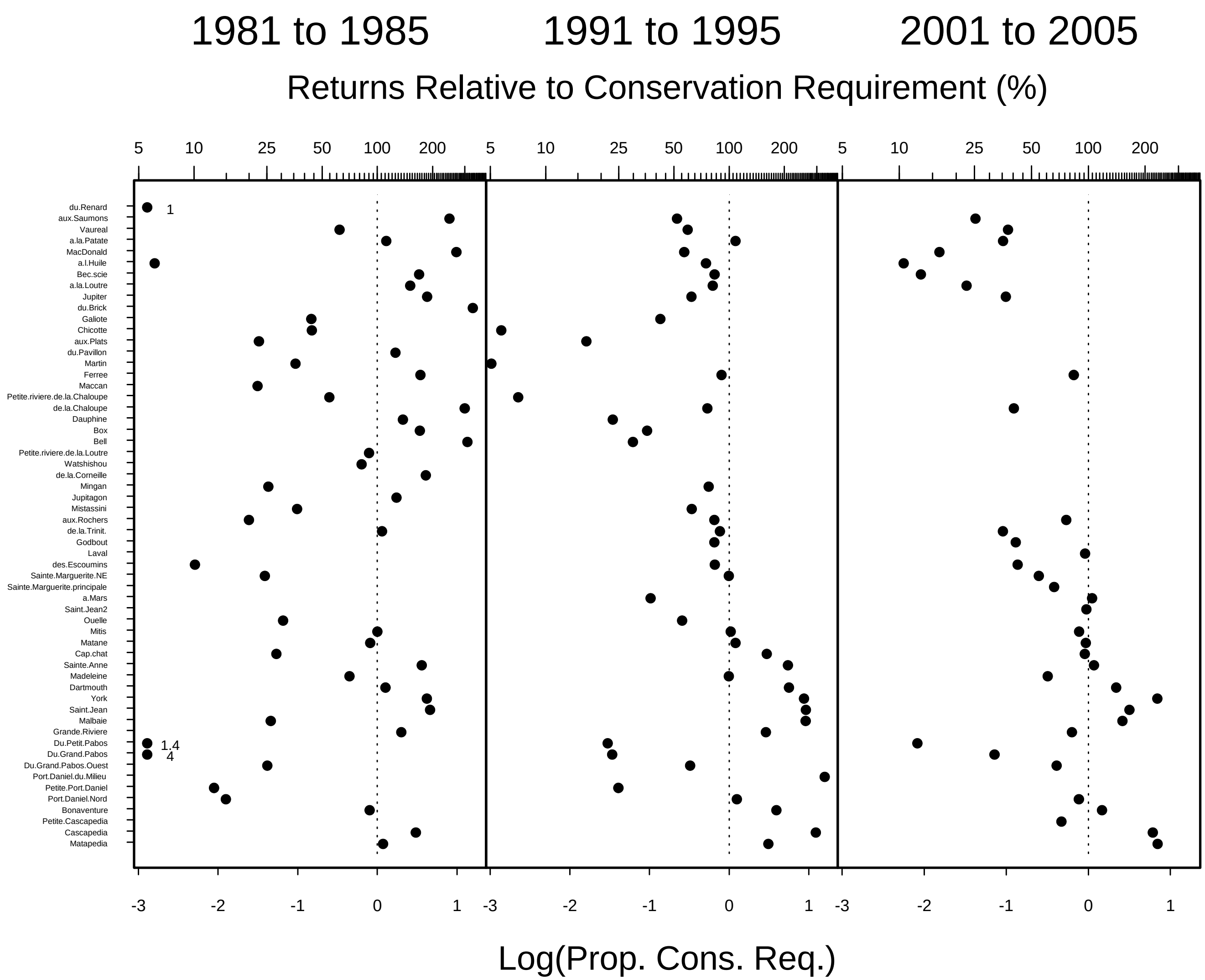

Figure 2. Five year mean numbers of large (dark points) and small (light points) salmon returning to rivers in Quebec as a percentage of the conservation spawner requirement for the river. Three time periods are shown. Spawner requirements for both size categories are not used for all rivers. Points that are outside the range of the graph are labelled with their value.

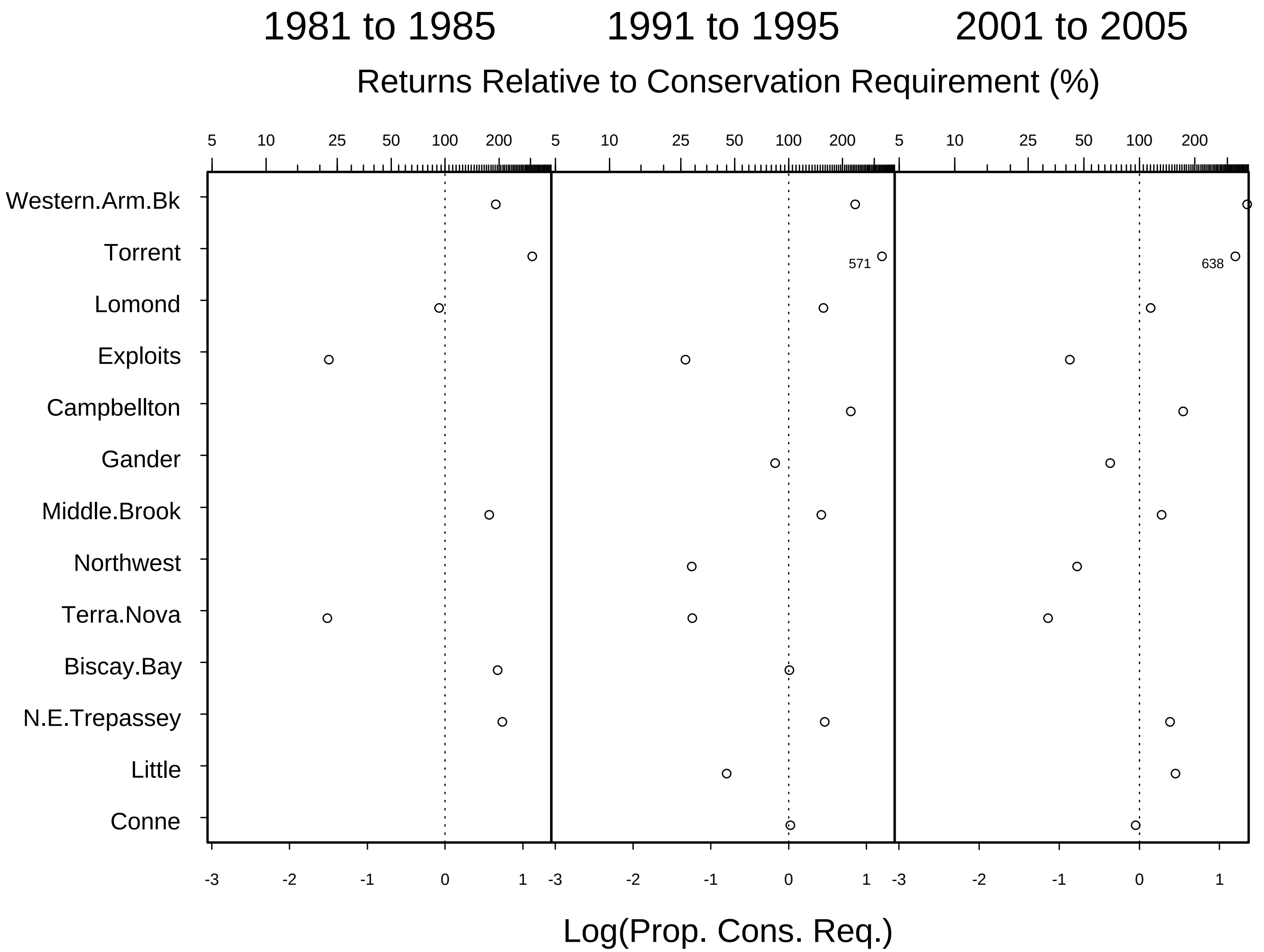

Figure 3. Five year mean numbers of large (dark points) and small (light points) salmon returning to rivers in Newfoundland/Labrador as a percentage of the conservation spawner requirement for the river. Three time periods are shown. Spawner requirements for both size categories are not used for all rivers. Points that are outside the range of the graph are labelled with their value.

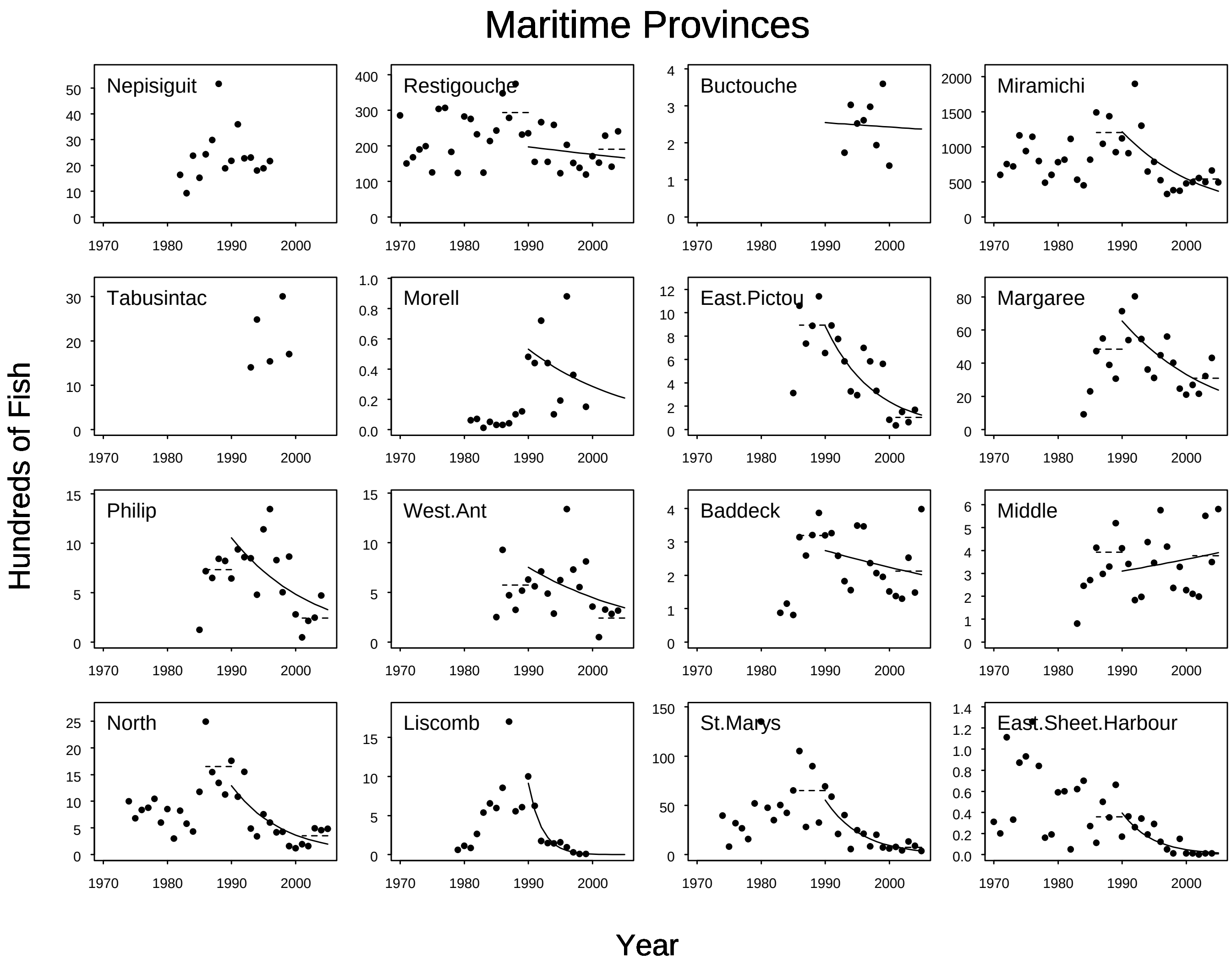

Figure 4. Trends in abundance of salmon populations in the Maritime Provinces from 1970 to 1990. The curved solid line shows the trend from 1990 to 2005 obtained from a log-linear model. The dashed lines show the 5-year average population sizes for the time periods ending in 1990 and 2005.

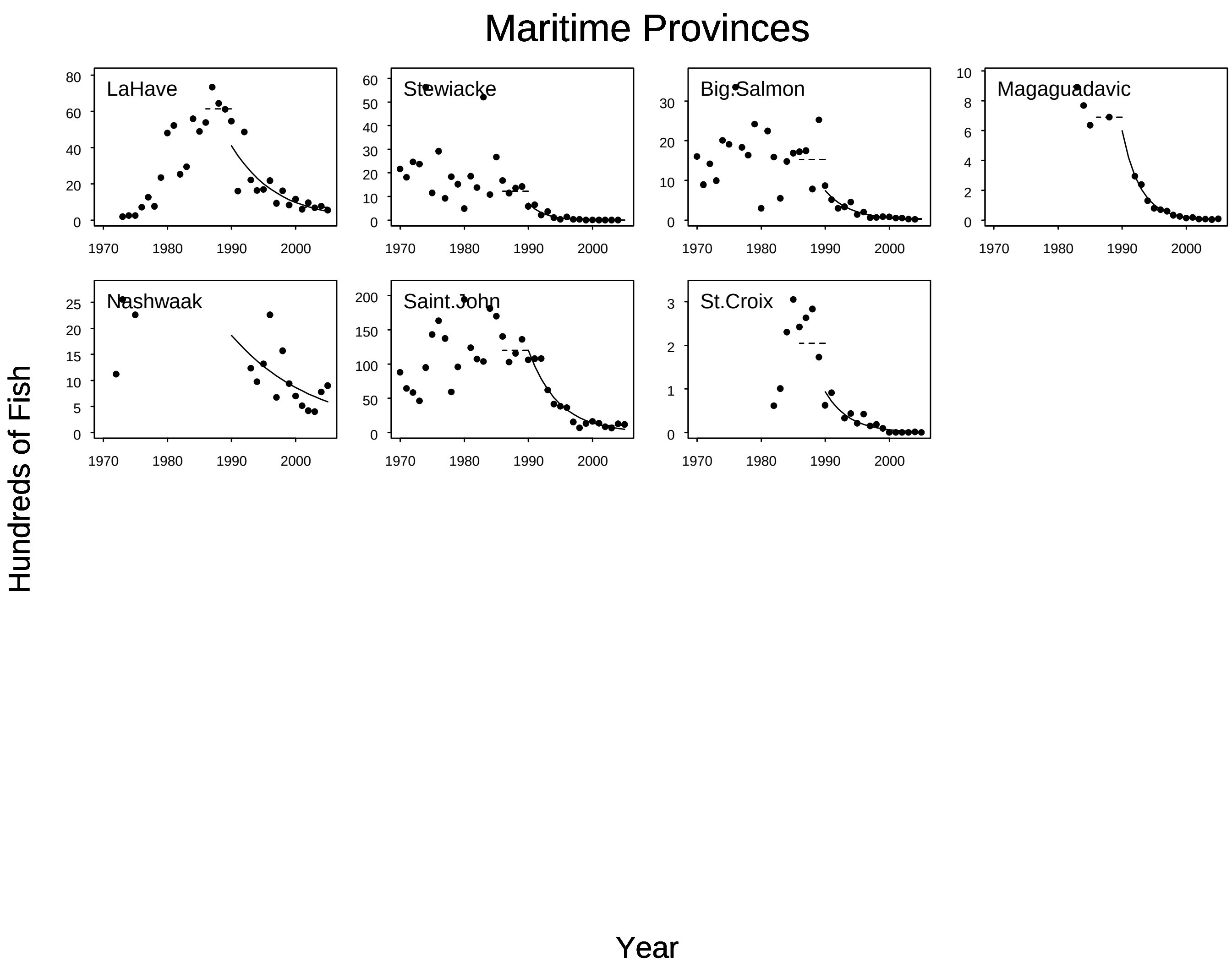

Figure 4 (con’t.). Trends in abundance of salmon populations in the Maritime Provinces from 1970 to 1990. The curved solid line shows the trend from 1990 to 2005 obtained from a log-linear model. The dashed lines show the 5-year average population sizes for the time periods ending in 1990 and 2005.

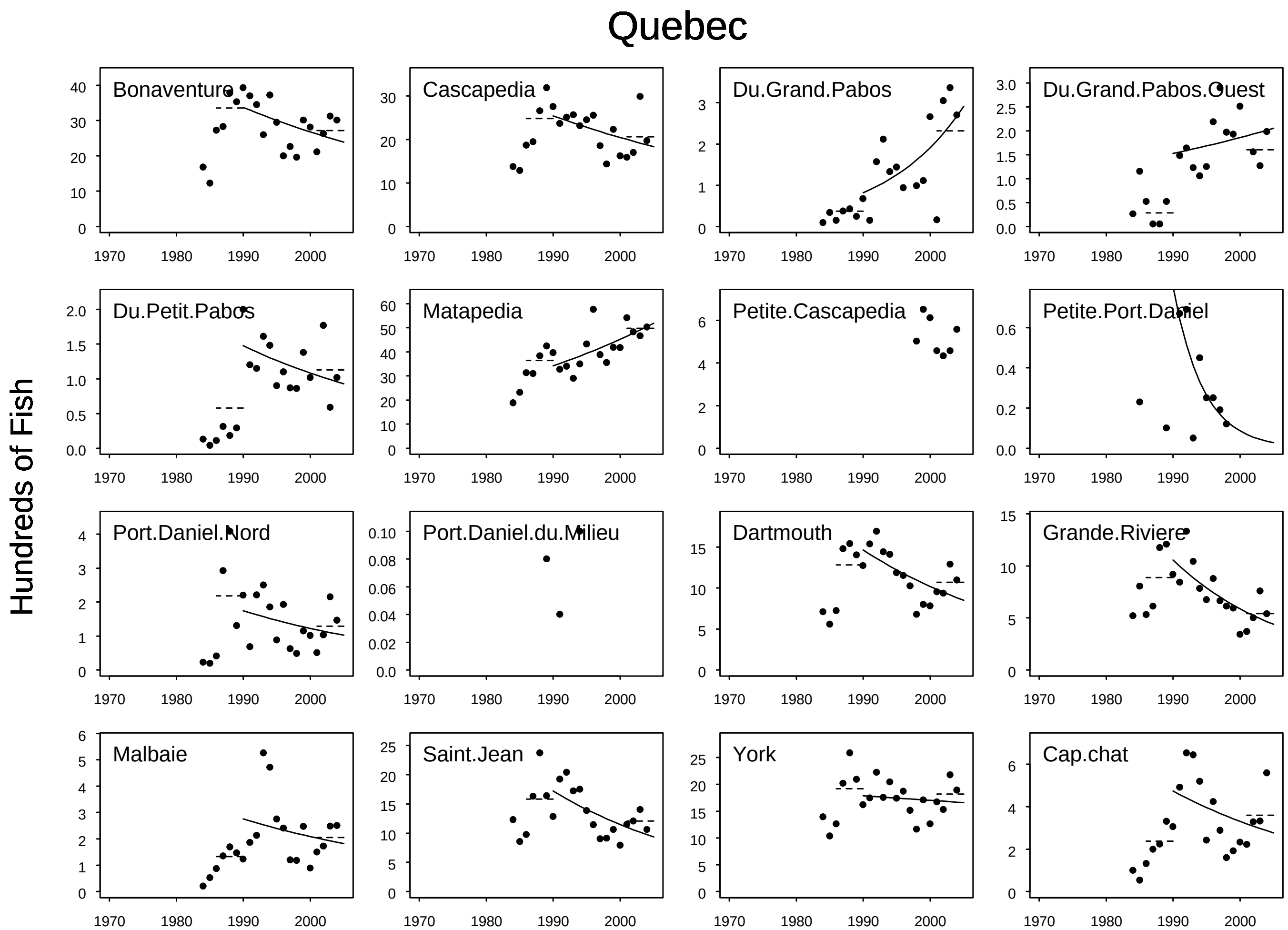

Figure 5. Trends in abundance of salmon populations in the Quebec from 1970 to 1990. The curved solid line shows the trend from 1990 to 2005 obtained from a log-linear model. The dashed lines show the 5-year average population sizes for the time periods ending in 1990 and 2005.

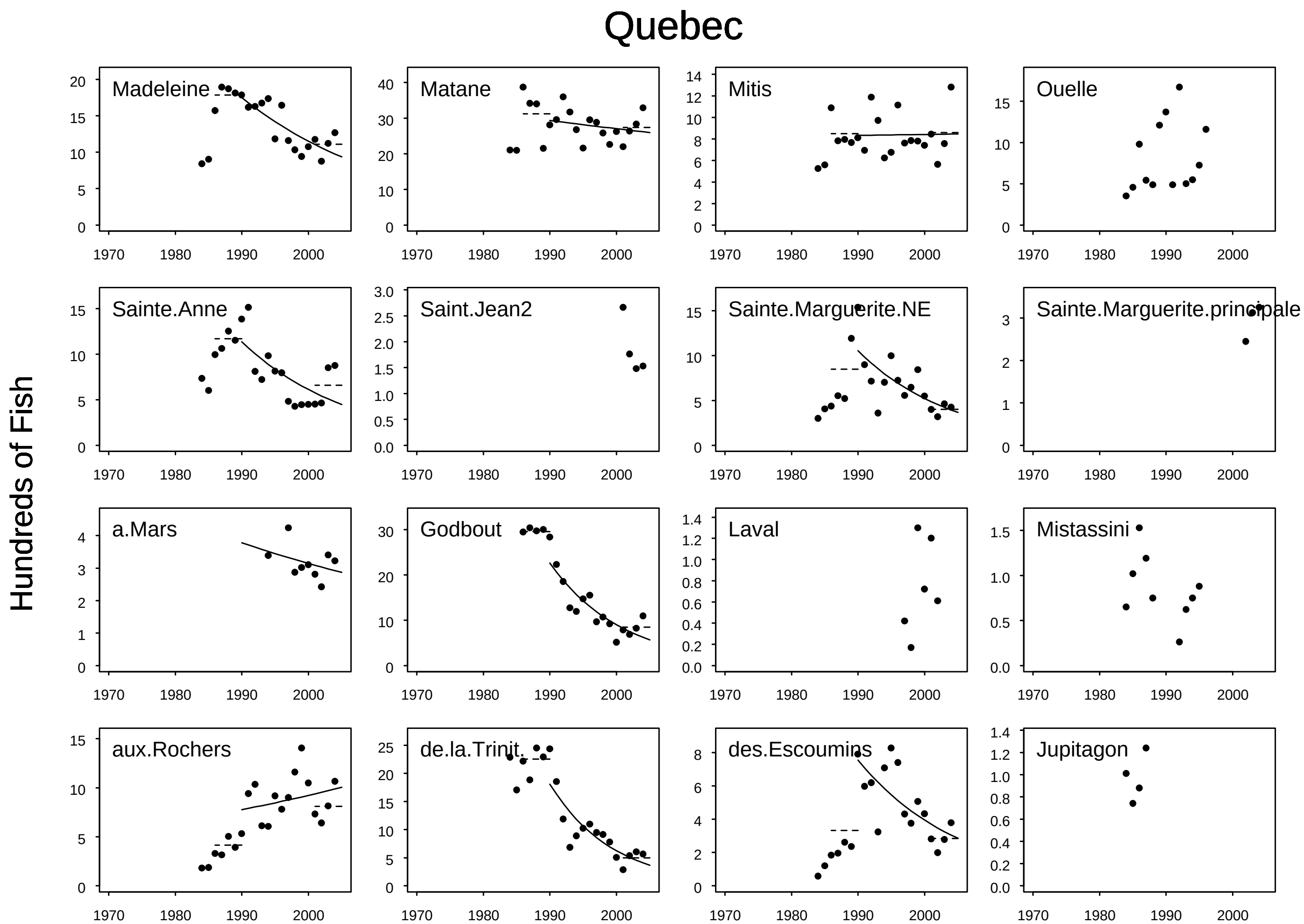

Figure 5 (con't.). Trends in abundance of salmon populations in the Quebec from 1970 to 1990. The curved solid line shows the trend from 1990 to 2005 obtained from a log-linear model. The dashed lines show the 5-year average population sizes for the time periods ending in 1990 and 2005.

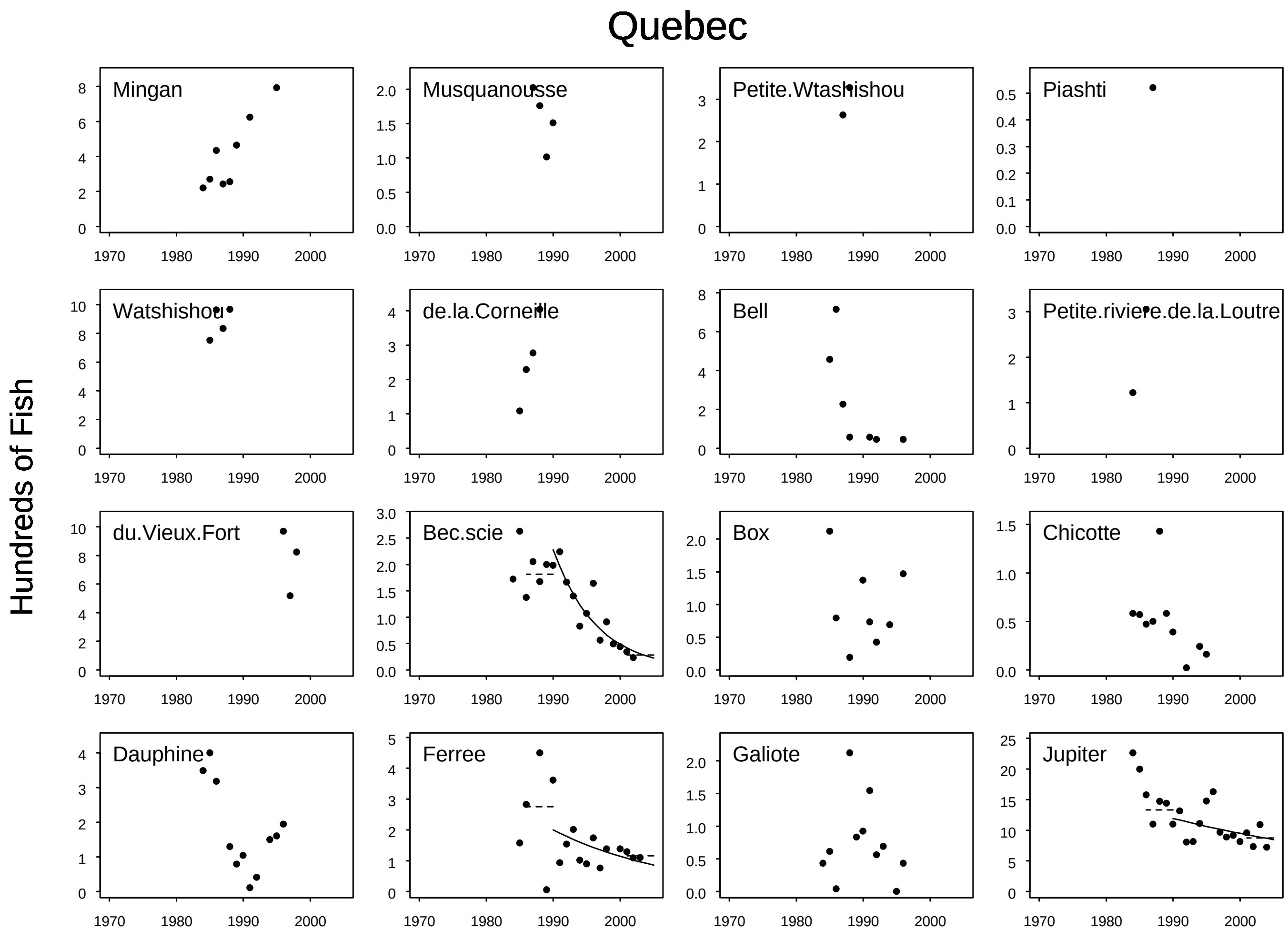

Figure 5 (con't.). Trends in abundance of salmon populations in the Quebec from 1970 to 1990. The curved solid line shows the trend from 1990 to 2005 obtained from a log-linear model. The dashed lines show the 5-year average population sizes for the time periods ending in 1990 and 2005.

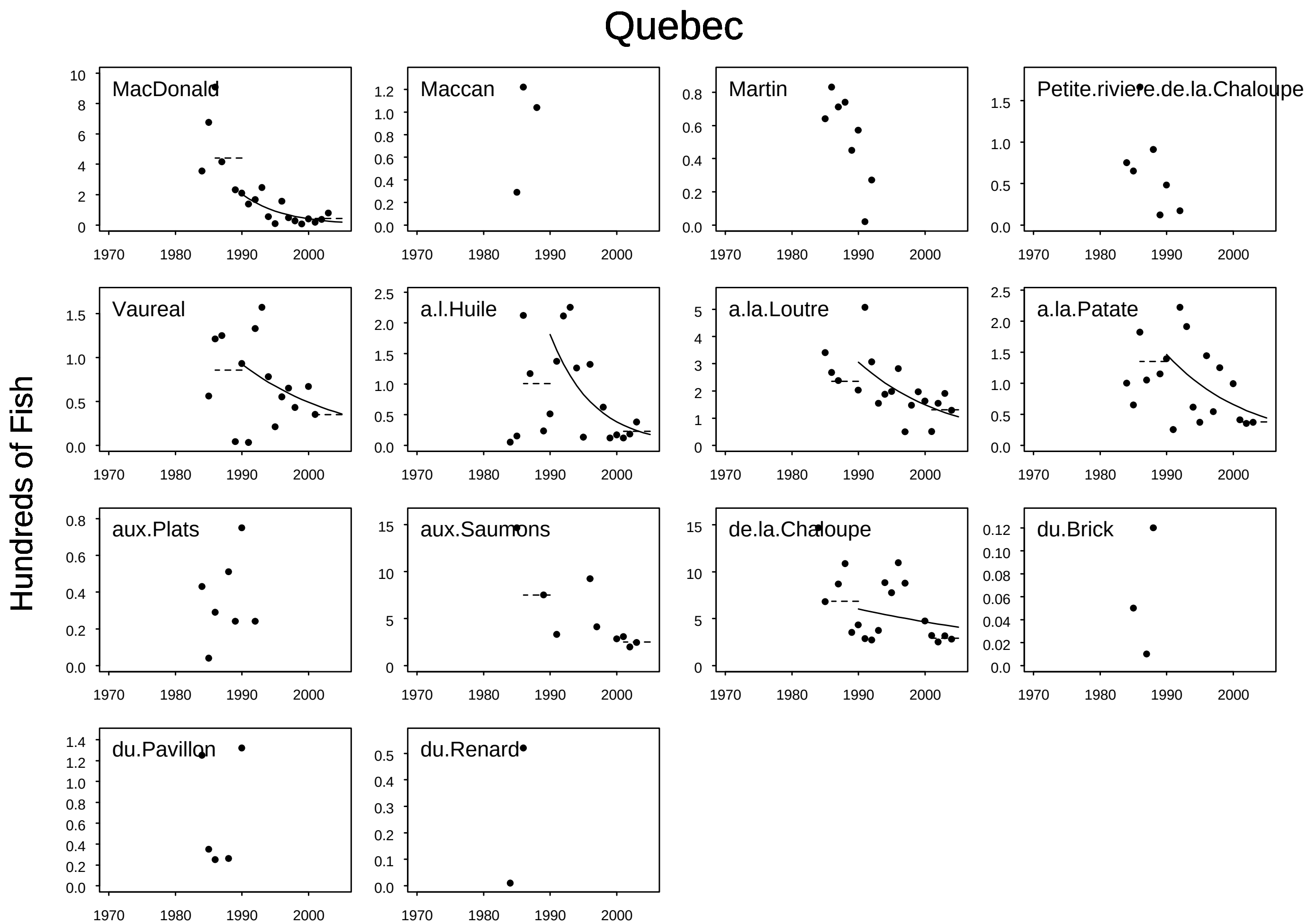

Figure 5 (con't.). Trends in abundance of salmon populations in the Quebec from 1970 to 1990. The curved solid line shows the trend from 1990 to 2005 obtained from a log-linear model assuming a lognormal error structure. The dashed lines show the 5-year average population sizes for the time periods ending in 1990 and 2005.

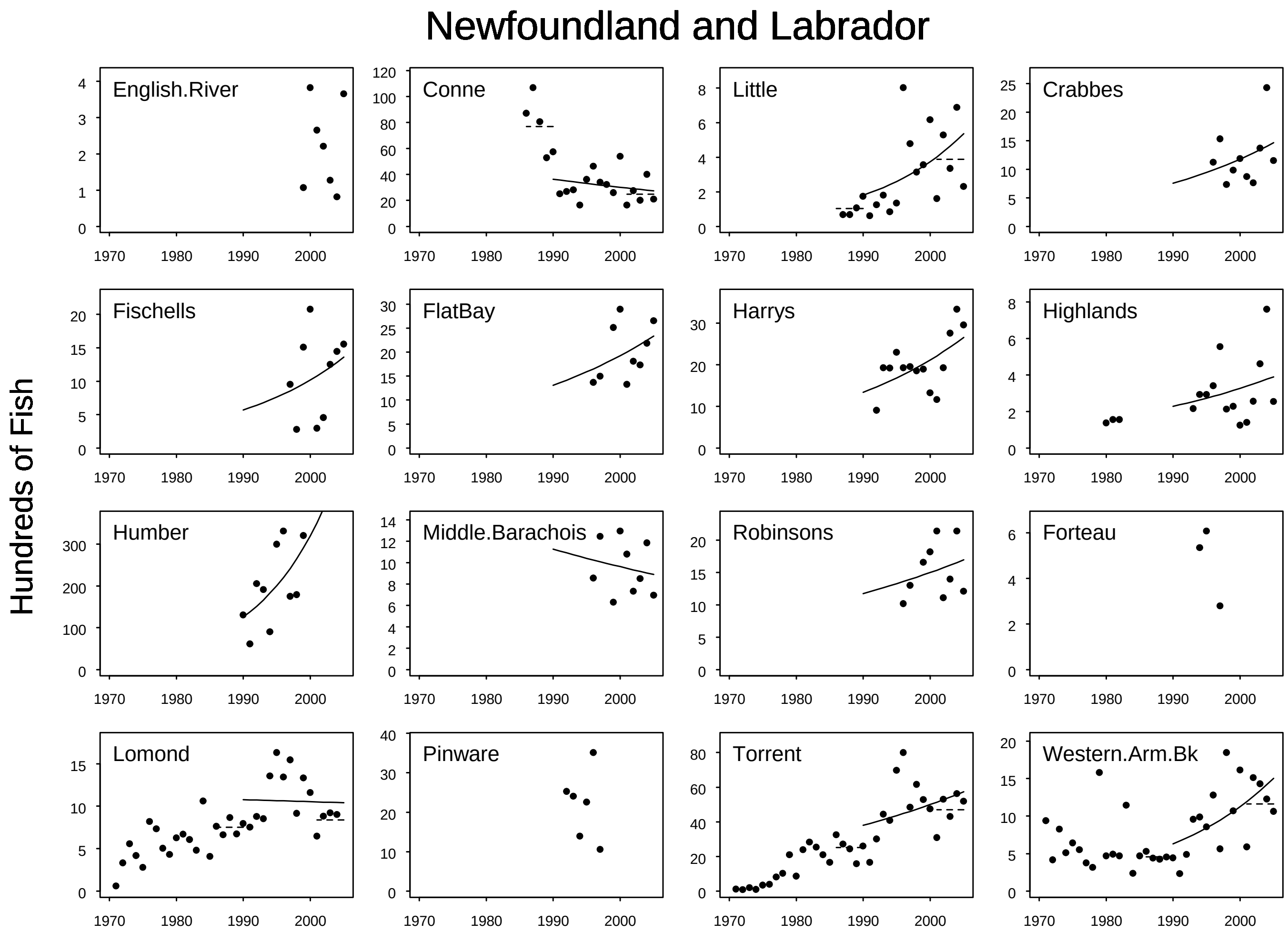

Figure 6. Trends in abundance of salmon populations in the Newfoundland and Labrador from 1970 to 1990. The curved solid line shows the trend from 1990 to 2005 obtained from a log-linear model. The dashed lines show the 5-year average population sizes for the time periods ending in 1990 and 2005.

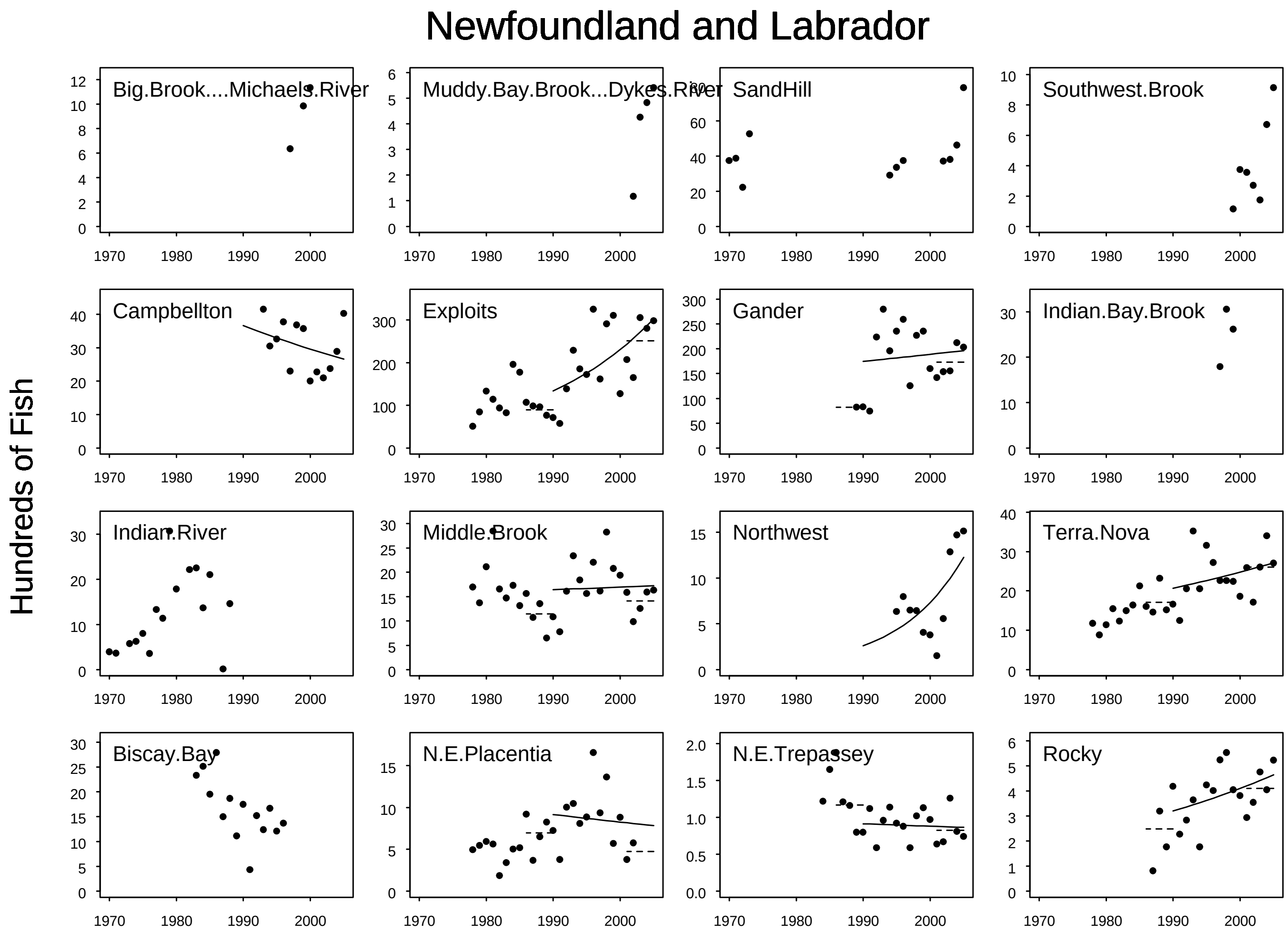

Figure 6 (con't.). Trends in abundance of salmon populations in the Newfoundland and Labrador from 1970 to 1990. The curved solid line shows the trend from 1990 to 2005 obtained from a log-linear model. The dashed lines show the 5-year average population sizes for the time periods ending in 1990 and 2005.

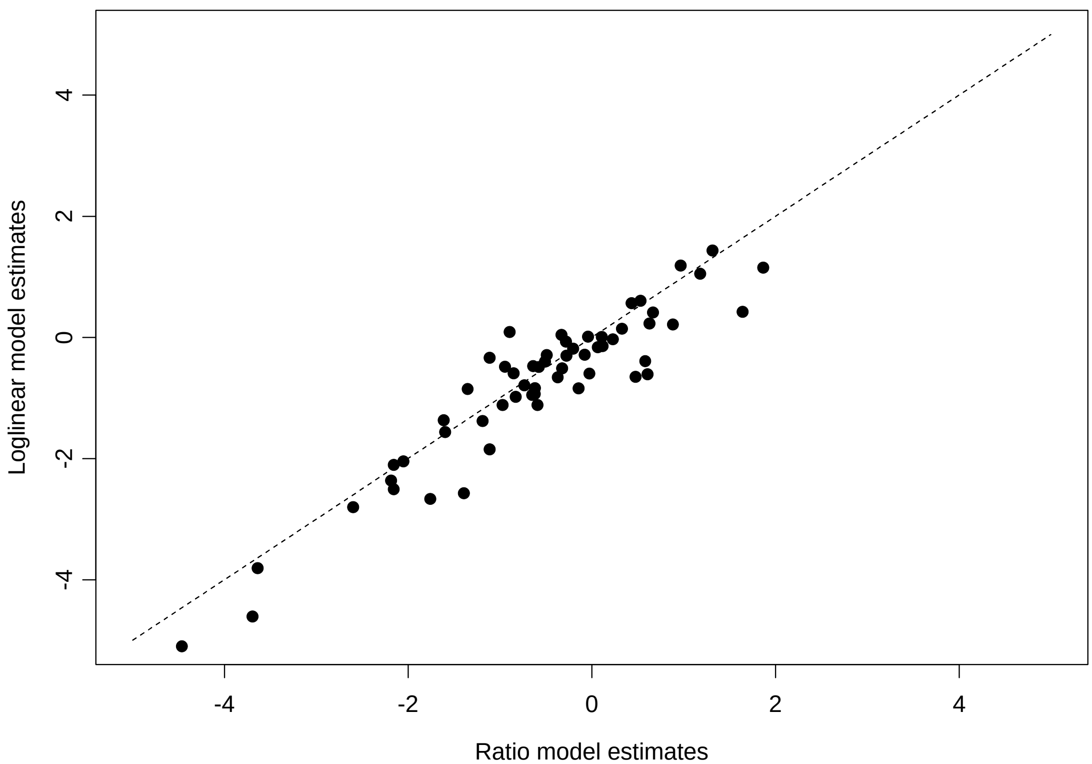

Figure 7. Comparison of the parameter estimates (log scale) obtained from two methods of estimating declines, the log-linear model and the ratio model. The dashed line is the 1:1 line.

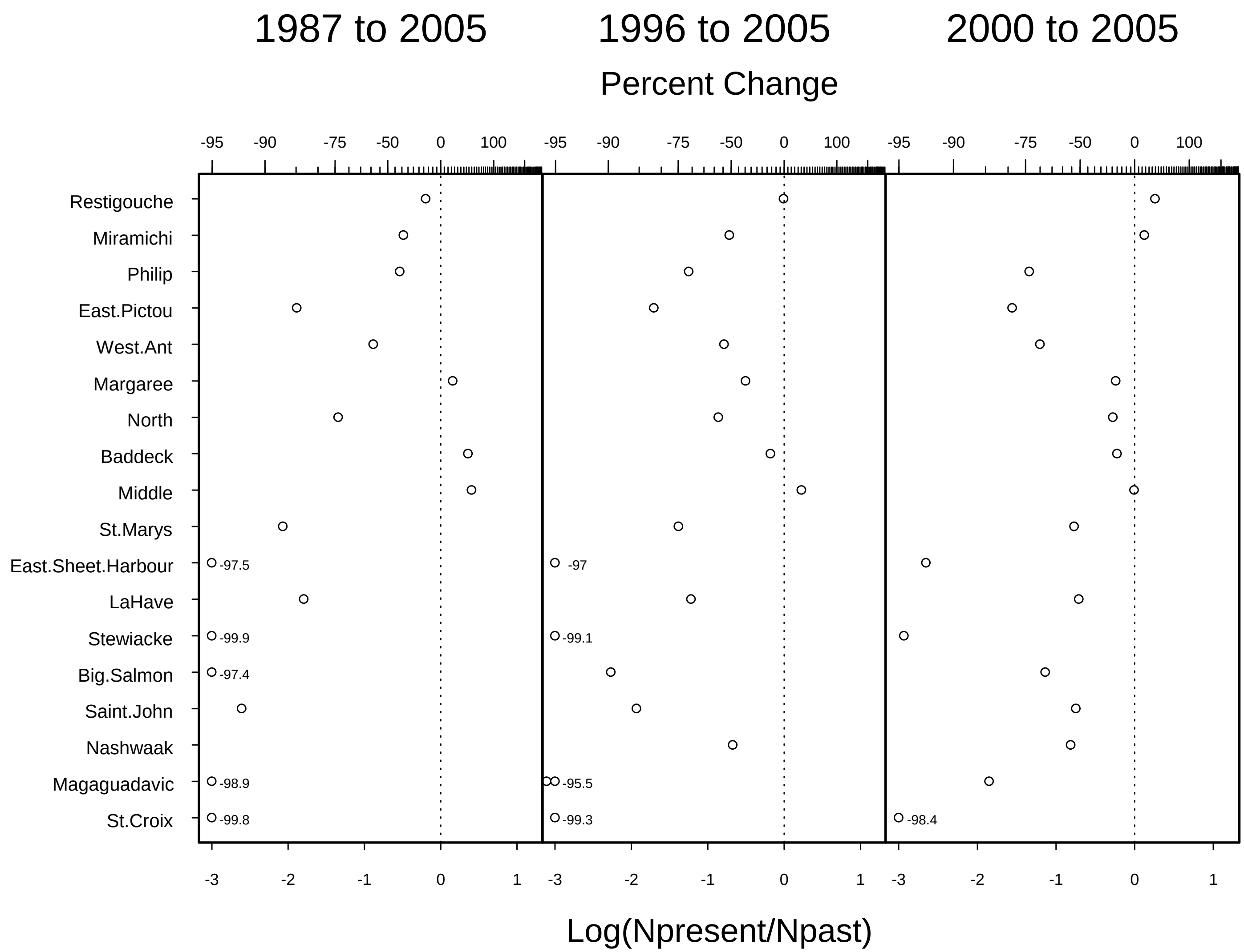

Figure 8. Changes in abundance of salmon populations in the Maritime Provinces over three time periods. Each point represents the change in 5-year mean population size (large and small salmon combined) for the time periods ending on the label years. Points that are outside of the range of the graph are labelled with their value.

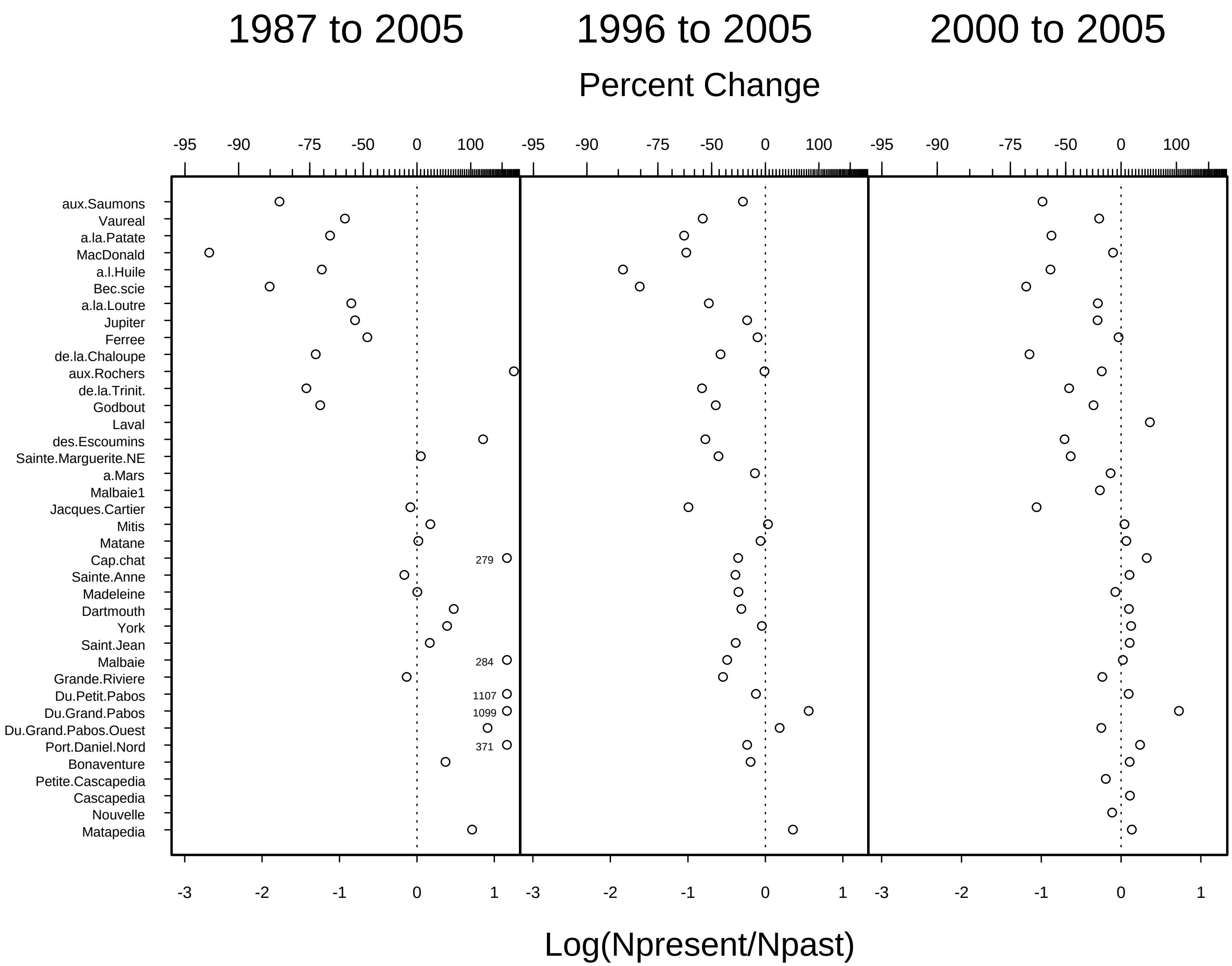

Figure 9. Changes in abundance of salmon populations in the Quebec over three time periods. Each point represents the change in 5-year mean population size (large and small salmon combined) for the time periods ending on the label years. Points that are outside of the range of the graph are labelled with their value.

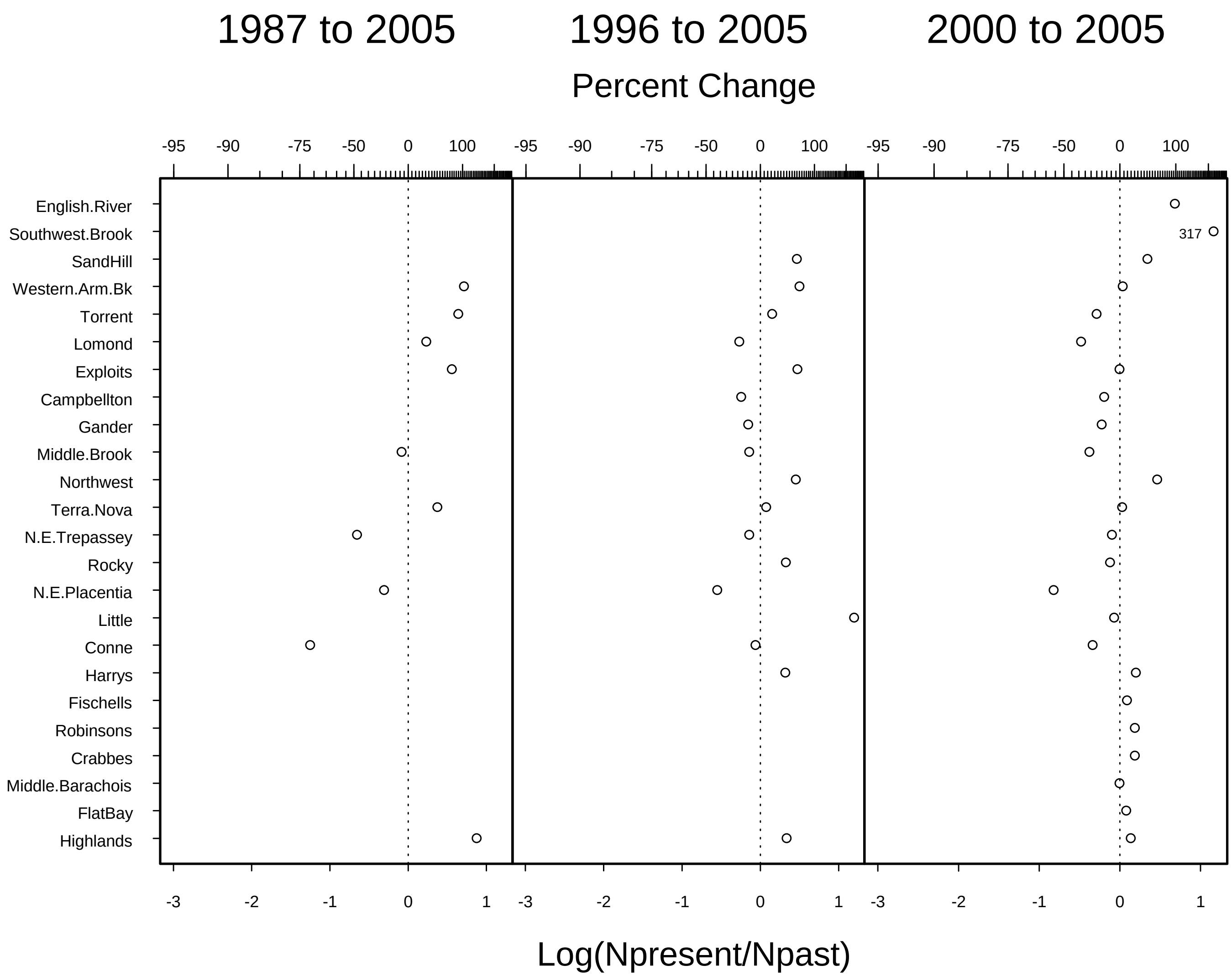

Figure 10. Changes in abundance of salmon populations in the Newfoundland/Labrador over three time periods. Each point represents the change in 5-year mean population size (large and small salmon combined) for the time periods ending on the label years. Points that are outside of the range of the graph are labelled with their value.

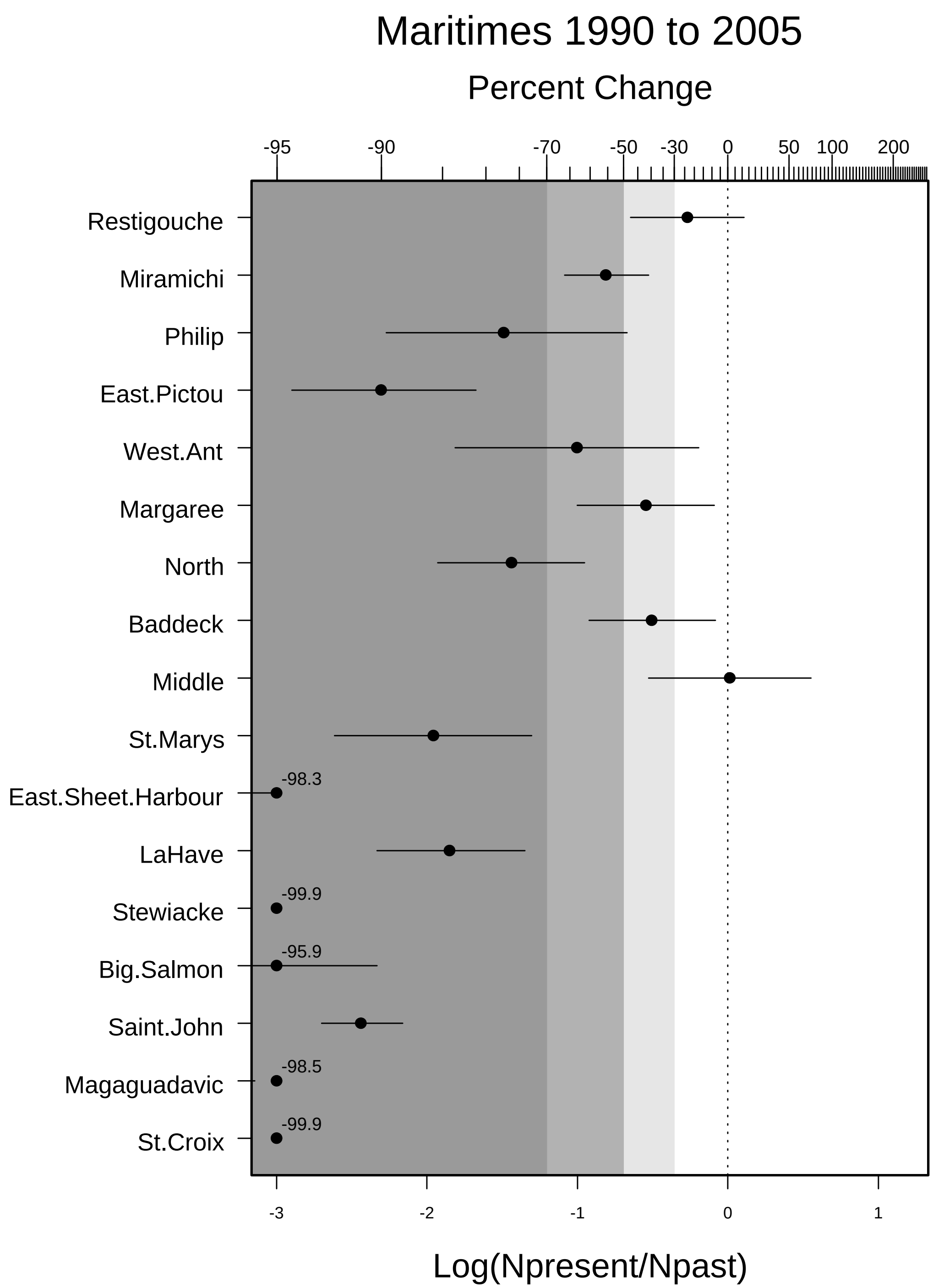

Figure 11. Three generation changes in abundance (large and small salmon combined) for salmon populations in the Maritime Provinces estimated using maximum likelihood and the ratio model. Each point represents the change in 5-year mean population size for the time periods ending in 1990 and 2005. Error bars are likelihood ratio-based 95% confidence intervals based on a lognormal error distribution.

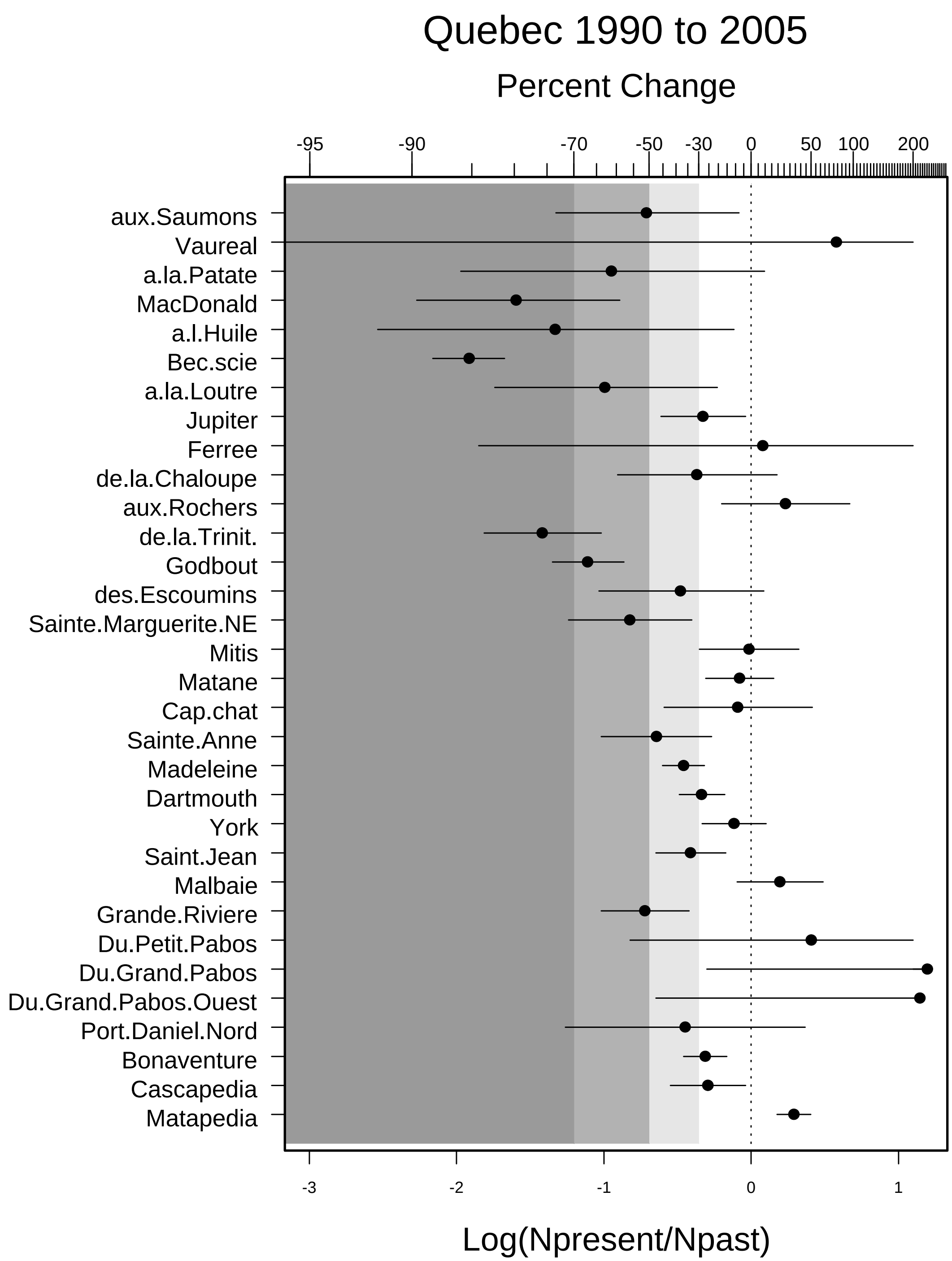

Figure 12. Three generation changes in abundance (large and small salmon combined) for salmon populations in Quebec estimated using maximum likelihood and the ratio model. Each point represents the change in 5-year mean population size for the time periods ending in 1990 and 2005. Error bars are likelihood ratio-based 95% confidence intervals based on a lognormal error distribution. Some error bars extend outside the range of the graph.

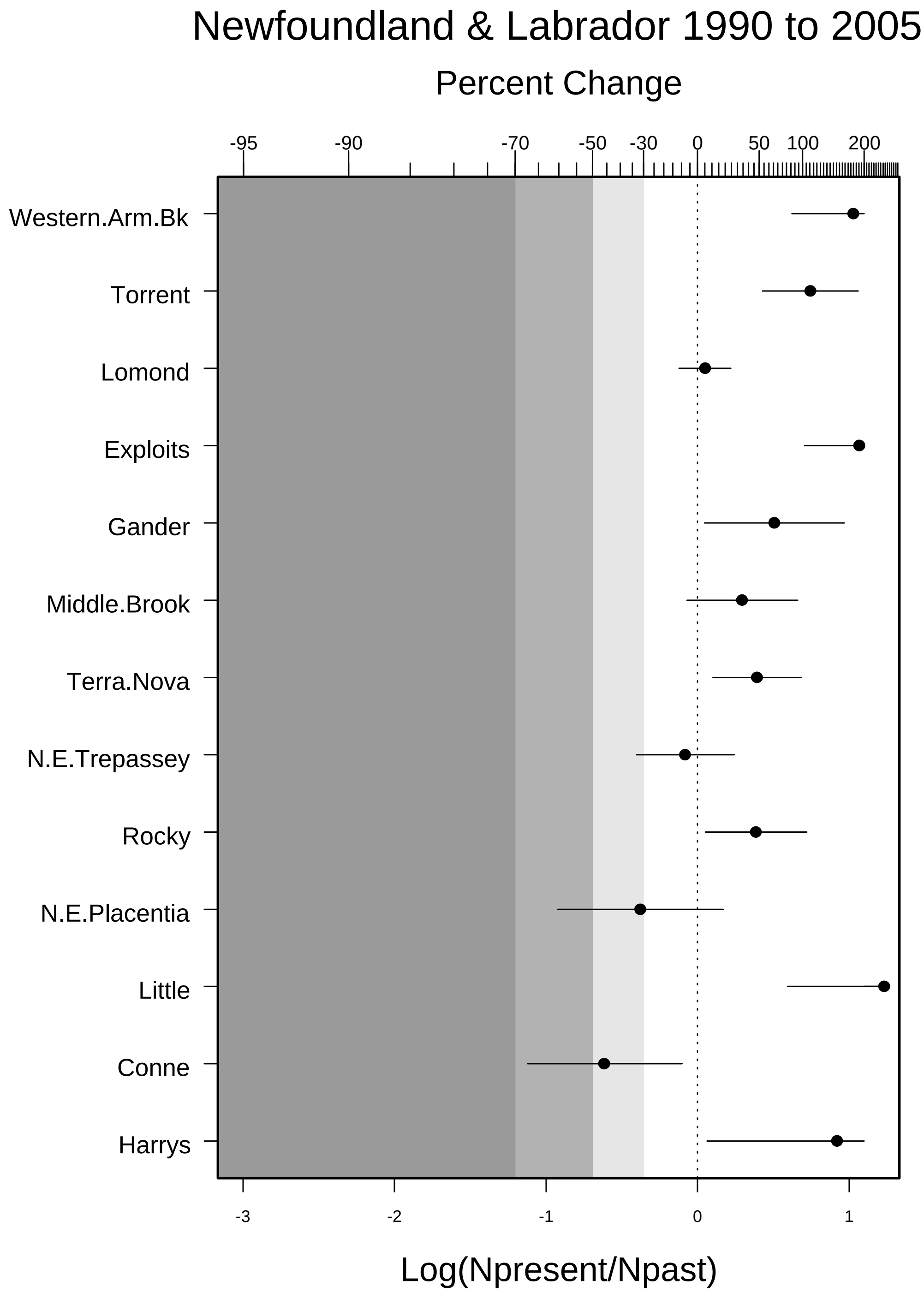

Figure 13. Three generation changes in abundance (large and small salmon combined) for salmon populations in the Newfoundland and Labrador estimated using maximum likelihood and the ratio model. Each point represents the change in 5-year mean population size for the time periods ending in 1990 and 2005. Error bars are likelihood ratio-based 95% confidence intervals based on a lognormal error distribution. Some error bars extend outside the range of the graph.

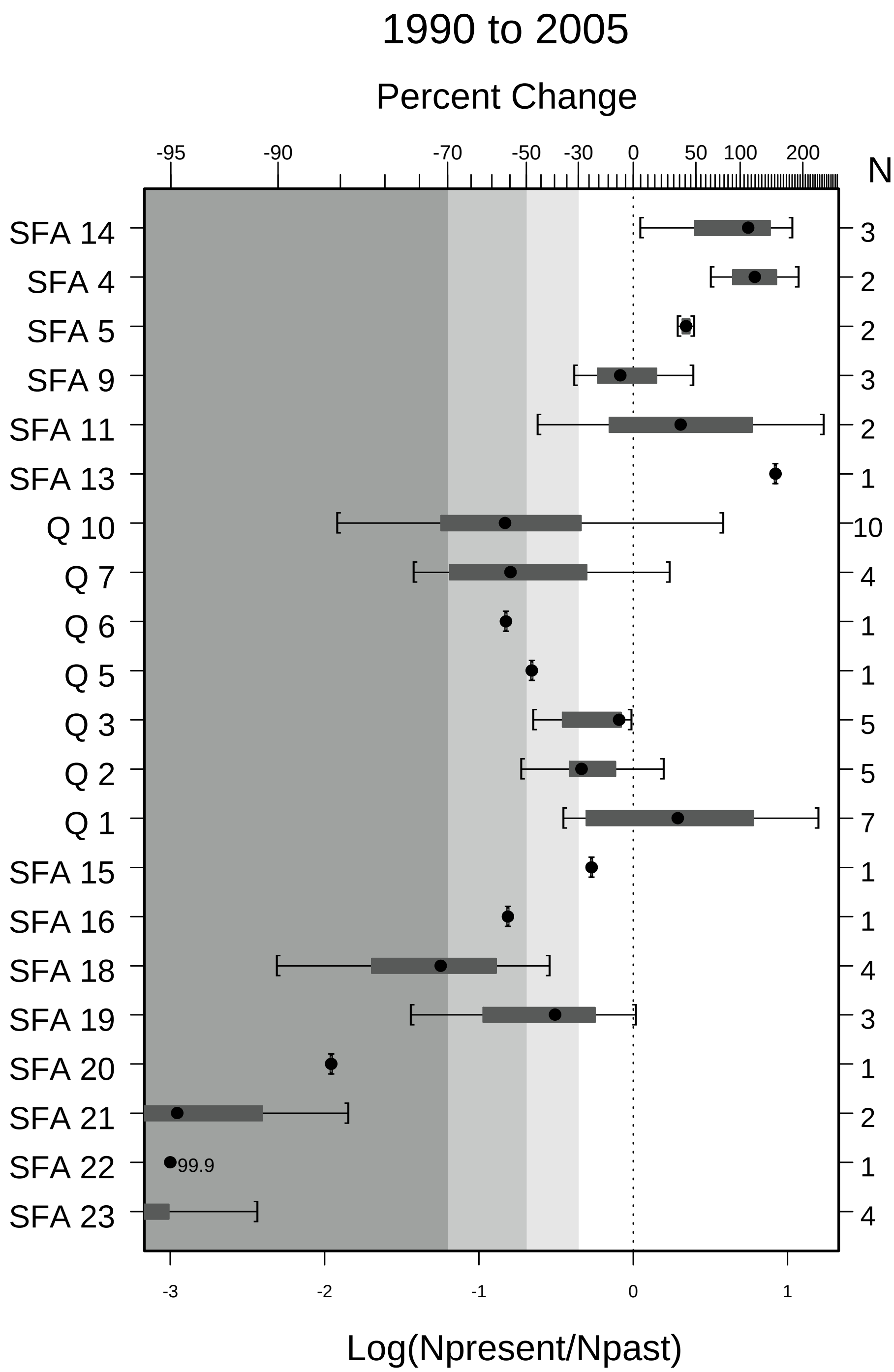

Figure 14. Summary of three generation change in population size for salmon populations by SFA, size categories combined. The point shows the median value for each SFA, the box shows the inter-quartile spread and the whiskers are drawn to the minimum and maximum. Points that are outside the range of the graph are labelled with their value.

Appendix 1: Descriptions and sources of data used in the analysis of abundance and trends.

Region	SFA	River	Data Type	Source
Maritimes	23	St.Croix	fish ladder counts	Jones et al. 2006
Maritimes	23	Magaguadavic	fish ladder counts	Jones et al. 2006
Maritimes	23	Nashwaak	fence counts/estimates	Jones et al. 2006
Maritimes	23	Saint John	fish lift counts	Jones et al. 2006
Maritimes	23	Big Salmon	model	Gibson et al . 2003c
Maritimes	22	Stewiacke	model	Gibson and Amiro 2003
Maritimes	21	LaHave	fish ladder counts	Amiro et al. 2006
Maritimes	21	East River (Sheet Hbr.)	fish ladder counts	Amiro et al. 2000
Maritimes	20	Liscomb	fish ladder counts	Amiro et al. 2000
Maritimes	20	St Marys	rec. catch; seine surveys	Amiro et al 2006
Maritimes	19	Middle	model; dive counts	Amiro et al. 2006
Maritimes	19	Baddeck	model; dive counts	Amiro et al. 2006
Maritimes	19	North	dive counts; rec. catch	Amiro et al. 2006
Maritimes	18	Margaree	angling catch, catch rates	Chaput et al. 2006
Maritimes	18	West Antigonish	angling catch	Chaput et al. 2006
Maritimes	18	Sutherlands	angling catch	Chaput et al. 2006
Maritimes	18	East Pictou	visual counts	Chaput et al. 2006
Maritimes	18	Philip	angling catch	Chaput et al. 2006
Maritimes	17	Morell	fishway count	Cairns et al. 1996
Maritimes	16	Buctouche	mark – recapture	Chaput et al. 2006
Maritimes	16	Miramichi	mark – recapture	Chaput et al. 2006
Maritimes	16	Northwest Miramichi	mark – recapture	Chaput et al. 2006
Maritimes	16	Southwest Miramichi	mark – recapture	Chaput et al. 2006
Maritimes	16	Tabusintac	mark – recapture	Douglas and Swasson 2000
Maritimes	15	Nepisiguit	partial fence count	Locke et al. 1997
Maritimes	15	Jacquet	partial fence count	Locke et al. 1997
Maritimes	15	Restigouche	angling catch	Chaput et al. 2006
Newfoundland/Labrador	13	Highlands	Fence count	O’Connell et al. 2005
Newfoundland/Labrador	13	FlatBay	Dive count	O’Connell et al. 2005
Newfoundland/Labrador	13	Middle Barachois	Dive count	O’Connell et al. 2005
Newfoundland/Labrador	13	Crabbes	Dive count	O’Connell et al. 2005
Newfoundland/Labrador	13	Robinsons	Dive count	O’Connell et al. 2005
Newfoundland/Labrador	13	Fischells	Dive count	O’Connell et al. 2005
Newfoundland/Labrador	13	Harrys	Fence count	O’Connell et al. 2005
Newfoundland/Labrador	13	Humber	Mark-recapture	O’Connell et al. 2005
Newfoundland/Labrador	13	Grand Bank	Fishway count	O’Connell et al. 2005
Newfoundland/Labrador	11	Conne	Fence count	O’Connell et al. 2005
Newfoundland/Labrador	11	Little	Fence count	O’Connell et al. 2005
Newfoundland/Labrador	9	N E Placentia	Fishway count	O’Connell et al. 2005
Newfoundland/Labrador	9	Rocky	Fishway count	O’Connell et al. 2005
Newfoundland/Labrador	9	N E Trepassey	Fence count	O’Connell et al. 2005
Newfoundland/Labrador	9	Biscay Bay	Fence count	O’Connell et al. 2005
Newfoundland/Labrador	5	Terra Nova	Fishway count	O’Connell et al. 2005
Newfoundland/Labrador	5	Northwest	Fence count	O’Connell et al. 2005
Newfoundland/Labrador	5	Middle Brook	Fishway count	O’Connell et al. 2005
Newfoundland/Labrador	5	Indian River	Fishway count	O’Connell et al. 2005
Newfoundland/Labrador	4	Indian Bay Brook	Fence count	O’Connell et al. 2005

Appendix 1 (con't.)

Region	SFA	River	Data Type	Source
Newfoundland/Labrador	4	Gander	Fence count	O'Connell et al. 2005
Newfoundland/Labrador	4	Gander Salmon Brook	Fishway count	O'Connell et al. 2005
Newfoundland/Labrador	4	Campbellton	Fence count	Downton & Reddin 2004
Newfoundland/Labrador	4	Exploits	Fishway count	O'Connell et al. 2005
Newfoundland/Labrador	4	Exploits Bishops Falls	Fishway count	O'Connell et al. 2005
Newfoundland/Labrador	4	Exploits Grand Falls	Fishway count	O'Connell et al. 2005
Newfoundland/Labrador	4	Exploits Red Indian Lake	Fishway count	O'Connell et al. 2005
Newfoundland/Labrador	4	Exploits Rattling Brook	Fishway count	O'Connell et al. 2005
Newfoundland/Labrador	14A	Lomond	Fishway count	O'Connell et al. 2005
Newfoundland/Labrador	14A	Torrent	Fishway count	O'Connell et al. 2005
Newfoundland/Labrador	14A	Western Arm Bk	Fence count	O'Connell et al. 2005
Newfoundland/Labrador	14B	Forteau	Fence count	Lowe & Mullins 1995
Newfoundland/Labrador	14B	Pinware	Mark-recapture	Mullins & Caines 1998
Newfoundland/Labrador	2	SandHill	Fence count	Reddin et al. 1996
Newfoundland/Labrador	2	Muddy Bay Brook: Dykes R.	Fence count	Reddin et al. 2005
Newfoundland/Labrador	2	Southwest Brook	Fence count	Reddin et al. 2005
Newfoundland/Labrador	2	Big Brook = Michaels R.	Fence count	Reddin et al. 2001a
Newfoundland/Labrador	1	English River	Fence count	Reddin et al. 2001b
Quebec	Q 1	Matapedia	Visual count	Anon. 2005.
Quebec	Q 1	Nouvelle	Visual count	Anon. 2005.
Quebec	Q 1	Cascapedia	Visual count	Anon. 2005.
Quebec	Q 1	Petite Cascapedia	Visual count	Anon. 2005.
Quebec	Q 1	Bonaventure	Visual count	Anon. 2005.
Quebec	Q 1	Port_Daniel_Nord	Visual count	Anon. 2005.
Quebec	Q 1	Petite Port-Daniel	Visual count	Anon. 2005.
Quebec	Q 1	Port-Daniel du Milieu	Visual count	Anon. 2005.
Quebec	Q 1	Du Grand Pabos Ouest	Visual count	Anon. 2005.
Quebec	Q 1	Du Grand Pabos	Visual count	Anon. 2005.
Quebec	Q 1	Du Petit Pabos	Visual count	Anon. 2005.
Quebec	Q 2	Grande Riviere	Visual count	Anon. 2005.
Quebec	Q 2	Malbaie	Visual count	Anon. 2005.
Quebec	Q 2	Saint_Jean	Visual count	Anon. 2005.
Quebec	Q 2	York	Visual count	Anon. 2005.
Quebec	Q 2	Dartmouth	Visual count	Anon. 2005.
Quebec	Q 3	Madeleine	Fishway count	Anon. 2005.
Quebec	Q 3	Mont-Louis	Visual count	Anon. 2005.
Quebec	Q 3	Sainte-Anne	Visual count	Anon. 2005.
Quebec	Q 3	Cap-chat	Visual count	Anon. 2005.
Quebec	Q 3	Matane	Fishway count	Anon. 2005.
Quebec	Q 3	Mitis	Fishway count	Anon. 2005.
Quebec	Q 3	Rimouski	Fishway count	Anon. 2005.
Quebec	Q 3	Ouelle	Visual Count	Anon. 2005.
Quebec	Q 5	Jacques-Cartier	Fishway count	Anon. 2005.
Quebec	Q 5	Malbaie	Fishway count	Anon. 2005.
Quebec	Q 6	Saint-Jean	Visual count	Anon. 2005.
Quebec	Q 6	a Mars	Fishway count	Anon. 2005.
Quebec	Q 6	Sainte-Marguerite principale	Visual count	Anon. 2005.
Quebec	Q 6	Sainte-Marguerite NE	Fishway count	Anon. 2005.

Appendix 1 (con't.)

Region	SFA	River	Data Type	Source
Quebec	Q 7	des Escoumins	Fishway count	Anon. 2005.
Quebec	Q 7	Laval	Fence count	Anon. 2005.
Quebec	Q 7	Godbout	Fishway count	Anon. 2005.
Quebec	Q 7	de la Trinité	Fishway count	Anon. 2005.
Quebec	Q 7	aux Rochers	Fishway count	Anon. 2005.
Quebec	Q 7	Mistassini	Fence count	Anon. 2005.
Quebec	Q 8	Jupitagon	Fence count	Anon. 2005.
Quebec	Q 8	Mingan	Fence count	Anon. 2005.
Quebec	Q 8	de la Corneille	Fence count	Anon. 2005.
Quebec	Q 8	Watshishou	Visual count	Anon. 2005.
Quebec	Q 8	Petite-Wtashishou	Visual count	Anon. 2005.
Quebec	Q 8	Piashti	Visual count	Anon. 2005.
Quebec	Q 8	Musquanousse	Visual count	Anon. 2005.
Quebec	Q 9	du Vieux Fort	Visual count	Anon. 2005.
Quebec	Q 9	Petite riviere de la Loutre	Visual count	Anon. 2005.
Quebec	Q 9	Bell	Visual count	Anon. 2005.
Quebec	Q 10	Box	Visual count	Anon. 2005.
Quebec	Q 10	Dauphine	Visual count	Anon. 2005.
Quebec	Q 10	de la Chaloupe	Visual count	Anon. 2005.
Quebec	Q 10	Petite riviere de la Chaloupe	Visual count	Anon. 2005.
Quebec	Q 10	Maccan	Visual count	Anon. 2005.
Quebec	Q 10	Ferree	Visual count	Anon. 2005.
Quebec	Q 10	Martin	Visual count	Anon. 2005.
Quebec	Q 10	du Pavillon	Visual count	Anon. 2005.
Quebec	Q 10	aux Plats	Visual count	Anon. 2005.
Quebec	Q 10	Chicotte	Visual count	Anon. 2005.
Quebec	Q 10	Galiote	Visual count	Anon. 2005.
Quebec	Q 10	du Brick	Visual count	Anon. 2005.
Quebec	Q 10	Jupiter	Visual count	Anon. 2005.
Quebec	Q 10	a la Loutre	Visual count	Anon. 2005.
Quebec	Q 10	Bec-scie	Count fence	Anon. 2005.
Quebec	Q 10	a l'Huile	Visual count	Anon. 2005.
Quebec	Q 10	MacDonald	Visual count	Anon. 2005.
Quebec	Q 10	a la Patate	Visual count	Anon. 2005.
Quebec	Q 10	Vaureal	Visual count	Anon. 2005.
Quebec	Q 10	aux Saumons	Visual count	Anon. 2005.
Quebec	Q 10	du Renard	Visual count	Anon. 2005.