Fisheries and Oceans Canada / Pêches et Océans Canada
Science / Sciences

C S A S **S C C S**

Canadian Science Advisory Secretariat / **Secrétariat canadien de consultation scientifique**

Research Document 2012/102 / **Document de recherche 2012/102**

Gulf Region / **Région du Golfe**

Estimated returns of Atlantic salmon (*Salmo salar*) to the Miramichi River and each branch, 1998 to 2011

Estimations des montaisons de saumon atlantique (*Salmo salar*) à la rivière Miramichi et pour chacun des affluents, 1998 à 2011

G. Chaput and S. Douglas

Fisheries and Oceans Canada / Pêches et Océans Canada
Science Branch / Direction des science
Gulf Region / Région du Golfe
P.O. Box 5030 / C.-P. 5030
Moncton, N.B. / N.-B.
E1C 9B6

ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Canada

Correct citation for this publication:

Chaput, G., and Douglas, S. 2012. Estimated returns of Atlantic salmon (*Salmo salar*) to the Miramichi River and each branch, 1998 to 2011. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/102. ii + 56 p.

ABSTRACT

A hierarchical Bayesian mark and recapture model is used to estimate returns of Atlantic salmon (*Salmo salar*) adults by size group to the Miramichi River and to each branch for 1998 to 2011. The model uses auxiliary data from counts of salmon at three headwater barrier fences to estimate returns annually for the early-run (prior to August 1) and for the whole year. Model fit is assessed by examining observed to predicted recaptures at three estuary trapnet locations. Retrospective analysis is used to assess the stability of previous years' estimates of returns as recent years observations are added to the model. Estimated returns using the hierarchical model are less uncertain and differ in some years from independent annual assessments. Future modifications to the model include incorporating angling catch and effort data and extending the model back to 1984 when mark and recapture programs were less intensive and for which angling data and barrier count information could be used to advantage to estimate the return of Atlantic salmon to the Miramichi River.

RÉSUMÉ

Un modèle bayésien hiéarchique de marquage et de recapture est utilisé pour évaluer les montaisons de saumon atlantique (*Salmo salar*) par groupe de taille à la rivière Miramichi et pour les deux affluents principaux pour les années 1998 à 2011. Ce modèle utilise des indicateurs auxiliaires d'abondances provenant de décomptes à des barrières en rivière pour évaluer les montaisons d'été (avant le 1^{e} août) et pour toute l'année. L'ajustement du modèle est vérifié en comparaison des observations et des valeurs prédites de recaptures aux trois filets-trappes dans l'estuaire. Une analyse rétrospective est présentée pour évaluer la stabilité des estimations annuelles antérieures lorsqu'on ajoute de nouvelles années d'observations. Les estimations de montaisons provenant du modèle hiéarchique sont plus précises et, pour certaines années, diffèrent de celles obtenues avec un modèle annuel non-hiéarchique. Des modifications futures à considérer incluent l'utilisation des indices de captures et des efforts de la pêche récréative ainsi que l'évaluation des montaisons antérieures commençant en 1984. Pour ce dernier travail, le programme de marquage et de recapture était moins élaboré et dans ce cas les indices d'abondance provenant de la pêche récréative et des barrières de dénombrement pourraient être utilisés davantage pour estimer les montaisons du saumon atlantique à la rivière Miramichi.

INTRODUCTION

The Miramichi River, located in central New Brunswick, has a maximum axial length of 250 km and drains an area of about 14,100 km^2. There are two major branches: the Northwest Branch covers about 3,950 km^2 and the Southwest Branch about 7,700 km^2 of drainage area (Bousfield 1955). The two branches drain into a common estuary and subsequently drain into the Gulf of St. Lawrence at latitude 47°N (Fig. 1).

The Miramichi River is considered to contain several stocks of Atlantic salmon (Saunders 1981). Separate branch assessments were introduced in 1992 to account for some of this diversity and for the differences in exploitation between the Northwest and Southwest branches. Aboriginal fisheries were historically conducted almost exclusively in the Northwest Miramichi (exploitation also occurs in the estuarial waters of the Miramichi River, downstream of the confluence of the two branches) and recreational fisheries exploitation also differs between the Northwest and Southwest branches.

Temporal stock distinctiveness has been highlighted as an important component of the Atlantic salmon resource (Saunders 1967). Early runs (prior to Aug. 1 in this paper; up to Aug. 31 in previous assessments) and late runs have different composition in terms of small and large salmon proportions. The early runs in both branches are also exploited more heavily than the late runs (Randall et al. 1990).

For fisheries management purposes, two size groups of salmon are defined. The small salmon category consists of fish less than 63 cm fork length and are generally referred to as grilse. These fish have usually spent only one full year at sea (one-sea-winter) prior to returning to the river but the size group may also contain some previously spawned salmon. The large salmon category consists of fish greater than or equal to 63 cm fork length. This size group is generally referred to as multi-sea-winter or just salmon and contains varying proportions of one-sea-winter, two-sea-winter and three-sea-winter maiden (first time) spawners as well as previous spawners (Moore et al. 1995).

In the context of the Miramichi, estimates of returns to each branch are desired. It is not possible to obtain absolute counts of salmon in the Miramichi due to its physical size. As a result, the use of partial capture techniques to sample the runs necessitates the use of mark and recapture models to estimate run sizes.

Since 1992, assessments of the returns of salmon to the Northwest and Southwest branches have been prepared. Returns by size group to the whole river were partitioned into Northwest and Southwest Miramichi returns. The most recent assessment is available in DFO (2010) and Chaput (2010).

MATERIALS AND METHODS

TRAPNETS

The trapnets used in the Miramichi are for the most part T-trap designs as used in the historical commercial salmon fishery and in the commercial gaspereau fishery. V-trap designs were used at the Northwest recaptured traps in some years. The T-trap designs evolved to include a back-channel linking the upper and lower traps in the late 1990s. Trapnet specific details are provided in Hayward (2001) and Chaput (2010).

The returns of salmon to the Miramichi can extend from the middle of May to early November. Since 1994, facility M26 (Millerton) is considered the DFO science index facility for the Southwest Miramichi whereas in the Northwest Miramichi, facility M05 (Cassilis) has become the DFO science index trapnet since 1998 (Fig. 2).

Processing of Catches at the trapnets

All fish captured at the trapnets were enumerated by species. Atlantic salmon were captured with a dipnet, placed in sampling boxes in water and measured for fork length (to the nearest 0.1 cm). Sex determination was made based on external characteristics and is considered unreliable prior to August. Wild fish were distinguished from hatchery origin fish on the basis of the presence of the adipose fin, this fin having been removed prior to stocking on the majority of hatchery produced juvenile salmon. Scale samples, for determination of age, were removed from the standard location (along the imaginary line joining the posterior of the dorsal fin and the anterior of the anal fin, two to four rows above the lateral line) from all large salmon and from varying proportions of small salmon. Scale samples were stored dry.

Prior to release, Atlantic salmon were marked with individually numbered blue Carlin tags (dimensions 9.5 mm by 4.6 mm by 1.0 mm thick) attached to the back just anterior to the dorsal fin with narrow gauge stainless steel wire. In most years, some salmon were released back to the river untagged because of injuries, to reduce stress during warm water events, or as a result of a catch in excess of the daily allotment of tags to be placed on small salmon. In those cases, the caudal fin was hole punched prior to releasing the fish, with upper or lower caudal punch specific to the branch. Caudal punching of the tail was restricted to the Northwest Cassilis trapnet (M05) and the Southwest Millerton trapnet (M26).

All salmon captured in trapnets (both at monitoring facilities and in the food fishery) were examined for the presence of a Carlin tag. In the case of Carlin tagged fish, the tag number, the size (small or large based on length), date and trapnet location where captured were recorded. Caudal punched fish and associated information were also noted before release at the index trapnets.

Food fishery catches at Eel Ground (M23 and M39 in Fig. 2) and Red Bank (M09 and M31 in Fig. 2) were sampled for number of salmon caught (by size) and number as well as sex of salmon harvested (by internal examination). Fish were examined for Carlin tags and when present the number was recorded prior to release or at sampling.

Treatment of Data

All the data were entered in spreadsheets and a coding hierarchy was derived for categorizing the fish sampled from the trapnets (Chaput 2010). Summaries by facility, size group and month of the catch, tagging and recapture histories were developed to construct the marking and recapture data series.

Barrier fence monitoring

There are three headwater protection barriers in the Miramichi, two in the Southwest Miramichi River (Dungarvon, Juniper) and one in the Northwest Miramichi River (Northwest Miramichi) (Fig. 1) (Madden et al. 1999). The two Southwest Miramichi barriers began operations in 1981 and the Northwest Miramichi began operation in 1988. Salmon are counted and contained into a holding pool where they are held and released to continue migrations upstream in late fall. Counts of salmon are obtained by small salmon and large salmon categories (Table 1).

Mark and recapture models

The estimation of the returns to the Miramichi is complicated by several factors including movement of tagged fish between branches and potentially different capture probabilities by trapnet. Returns to the branches are based on returns at the recapture locations. It was assumed that there was 10% mortality from tagging and handling (Chaput et al. 2000). Annual and hierarchical Bayesian models (Appendix 1) are used to estimate the returns of salmon by size group, to the Miramichi and to the Southwest and Northwest Miramichi branches separately (Chaput 2010).

Following on recommendations from a previous review in March 2010 (Chaput 2010; DFO 2010), the counts of fish at the headwater barriers in the Northwest Miramichi (NWMiramichi) and at the Dungarvon River barrier of the Southwest Miramichi (SWDungarvon) were considered as indices of the early run components of each branch (early run is prior to August 1). The counts at the Juniper barrier in the Southwest Miramichi are considered to be an index of total run to the Southwest Miramichi. In addition, the data for 2010 and 2011 for the Juniper barrier are considered incomplete due to the intermittent monitoring operations and these years were excluded from the version of the model used in 2011.

Data for 1998 to 2011

The 1998 to 2011 mark and recapture data were verified, and corrected (Tables 2 and 3).

Changes from most recent assessment (Chaput 2010)

Salmon sampled at trapnets subsequently move between branches. In previous years, all fish captured and released from the two index trapnets were marked before release in order to identify their state of capture, first time catch or previously caught. This was done to address the issue of repeated catches at the trapnets. The estimates of returns to each branch and overall were based on the first time catch only. Carlin tagged fish were treated in the same way, first time recaptures were treated as valid recaptures if the tagged fish originated from another tagging trapnet. However, multiple recaptures of such fish, as for example, a salmon tagged in the NW Miramichi at Cassilis and seen again a second or more time at the SW Miramichi trapnet at Millerton were excluded from the recapture data vector.

In 2011 and in a few other years, warm water events necessitated the release of fish from the trapnet without marking. Some of these unmarked fish released from the trapnet could have been captured again although it would not be possible to know. In addition, tail punching ceased in 2011 to reduce stress on fish, previous experience indicated that in some cases, caudal punches resulted in excessive fraying and damage to the caudal fin. For 2011, multiple recaptures of Carlin tagged fish were included in the recapture categories as multiple catches of unmarked fish could not be excluded.

The models now estimate the abundance of unmarked fish in the system, with total return being the sum of unmarked and marked animals.

RESULTS AND DISCUSSION

RETROSPECTIVE PATTERNS

When hierarchical models are used, there could be changes to the estimates of abundance of previous years as new data are added because the annual estimates of tag movement rates, trapnet efficiencies, and proportions of runs at barriers are influenced by information from all years through the hyperparameter distributions. When the mark and recapture data are highly informative, the estimates over time are expected to be stable. When this information is weak or absent, the annual estimates may vary as additional years of data are added.

Chaput (2010) used the hierarchical model assuming that the headwater barrier counts were indices of total returns to each corresponding branch. This model was applied sequentially to the data from 1998 to 2009, from 1998 to 2010 and from 1998 to 2011. Estimates of abundance by size group to the Miramichi River and to each of the Northwest and Southwest branches are shown in Tables 4a to 4c and Figures 3a to 3c.

For the Miramichi River overall, there is no retrospective pattern and no important changes in the estimates of small salmon returns (Fig. 3a). For large salmon, the estimates for the years 2004 to 2006 increased (by 13% to 19% from 2009 to 2011) due primarily to the addition of the 2011 data (Table 4a; Figure 3a).

The retrospective patterns for the estimates of abundance for the Southwest Miramichi are similar to those of the Miramichi overall with no important differences in small salmon estimates but higher abundance estimates for large salmon when the 2011 data are included for the 2004 to 2006 years (Table 4b; Figure 3b). For the Northwest Miramichi, small salmon abundance estimates are similar among model runs and large salmon abundance estimates are similar although there is a slight and consistent decrease in abundance estimates for 1998 to 2009 when data from 2010 and 2011 are used, but these differences are negligible when accounting for the uncertainty of the estimates (Table 4c; Figure 3c).

REVISED MODEL FOR 2011

Following on recommendations from a previous review in March 2010 (Chaput 2010; DFO 2010), the counts at the headwater barriers in the Northwest Miramichi and in the Dungarvon River were assumed to be an index of the early run (prior to August 1) to each branch whereas the counts at the Juniper barrier in the Southwest Miramichi were considered to be an index of the run for the whole season. This choice is based on an analysis of tagged salmon recovered at the headwater barriers for the period 1995 to 2004 which indicated that 83% and 84% of the tags recovered at the Northwest Miramichi barrier and the Dungarvon River barrier, respectively, were from salmon tagged prior to August 1 (J. Hayward, DFO, unpublished data). Of the recaptured salmon at the Juniper barrier, 70% had been tagged prior to August 1.

In addition, the Juniper barrier has not operated as consistently during the year in 2010 and 2011 and the counts are considered partial counts and not exchangeable with the previous years. For this reason, the model used in 2011 excludes the Juniper barrier data for 2010 and 2011.

These changes in treatment of the barrier indices had minimal effect on the estimates of abundance for small salmon and large salmon from the Miramichi River overall, and for each of the branches (Tables 5a-c; Figures 4a-c). The median estimates for large salmon for 2011 for the Miramichi overall and the Southwest Miramichi are higher with the revised model structure but the median value is contained within the interquartile range of the estimate uncertainty (Fig. 4a,-b). There are minimal difference in estimates for the Northwest Miramichi (Fig. 4c; Table 5c).

The 2011 version of the model was retained in all subsequent analyses.

MODEL DIAGNOSTICS

Prediction of recaptures at trapnets

The predicted versus observed recaptures of small salmon and large salmon at the SW Millerton, NW Cassilis, and the NW RedBank trapnets are summarized in Figure 5.

Overall, the hierarchical model adequately (within the 95% B.C.I.) predicted recaptures by size group and trapnet location with a few discrepancies. In most cases, the observed recaptures were within the interquartile range (25th to 75th percentile) of the predicted recaptures (Fig. 5). Important discrepancies, with observed recaptures outside the 95% B.C.I. range, were noted for recaptures of SW Miramichi lower trapnet large salmon at the SW Millerton trapnet in 2007 (one recapture versus median predicted recapture of 10), recaptures of SW Millerton tagged small salmon at the NW Red Bank trapnets in 2000 and 2002 (observed less than predicted in 2000, observed greater than predicted in 2002) (Fig. 5).

Model convergence and posterior distributions

The tools provided in OpenBUGS were used to assess model convergence and posterior distributions (Spiegelhalter et al. 2010). A burn-in of 50,000 to 100,000 MCMC draws was used for small salmon and large salmon, respectively. Posterior distributions were summarized from a subsequent 20,000 MCMC draws using two chains and keeping every fifth MCMC draw. The history of the MCMC draws, the BGR (Gelman-Rubin statistic) plots and the posterior densities of the estimates for the total returns to the Miramichi River, as an example, are shown in Figure 6.

The BGR diagnostic is calculated when multiple chains of initial values are used. The basic idea is to generate multiple chains starting at over-dispersed initial values, and assess convergence by comparing within- and between-chain variability over the second half of those chains. The ratio R = B / W (where B is the width of the central 80% interval of the pooled chains and W is the average width of this interval within individual chains) should be greater than 1 if the starting values are suitably overdispersed; it will also tend to 1 as convergence is approached. R must converge to 1 and B and W should have converged to stability.

Convergence was considered to have been attained. The MCMC draws occurred over a stable range of values and the BGR plots indicate convergence over the sampling history (Fig. 6). The posterior distributions were unimodal and strongly defined relative to the uniform uninformative prior assumptions (Fig. 6). The 2011 posterior distribution estimate for large salmon was less smooth than in other years, suggesting that there was somewhat more relative uncertainty than for other years (Fig. 6).

Shrinkage resulting from hierarchical modeling relative to annual models

Hierarchical models of the type described in this paper are proposed as a means of benefiting from experience in previous years (Rivot and Prévost 2002; Chaput 2010). Annual models treat the mark and recapture experiments as if nothing was known about the parameters of interest, in particular the movement of fish between branches and the efficiency of the index trapnets. Under the hierarchical model structure, the information from other years can be considered as prior information, before the mark and recapture experiment is conducted. In the absence of useful information in a given year with which to estimate the parameters of interest, the prior information is used. The importance of this prior information versus the amount of information contributed by the annual experiment is described by the change in these estimates, termed shrinkage, based on an annual model that ignores all prior experience versus the hierarchical model.

The estimates of abundance from the hierarchical model have less uncertainty, expressed as the coefficient of variation, in all years and for both size groups (Fig. 7). For the estimates of abundance for the Miramichi, the hierarchical and annual estimates are similar for small salmon for 1998 to 2004 (there was a large amount of information in the annual mark and recapture experiments for those years) but the shrinkage is very important for the 2005 to 2011 estimation years (Fig. 7). The shrinkage for large salmon is less severe, in terms of the median value but the coefficient of variation is much lower from the hierarchical model estimates (Fig. 7).

For the Southwest Miramichi, the hierarchical and annual estimates for small salmon differ the most and the shrinkage is most important for the 2005, 2007, 2008 and 2010 assessment years (Fig. 7). Even if the median estimate of small salmon abundance for 2009 is similar for the two models, the coefficient of variation is greatly reduced (24%) with the hierarchical model compared to the annual model (CV 111%) (Fig. 7). For large salmon, estimates differ the most in 2005, 2007 and 2011 (Fig. 7).

For the Northwest Miramichi, estimates for large salmon are most different in 2005 (when the NW Red Bank trapnets did not operate), 2003, 2008 and 2010 (Fig. 7). For small salmon, estimates in 2005 were not reasonable with the annual model, and in other years, the estimates from the hierarchical model are generally higher than with the annual model (Fig. 7). Again, the CVs are much lower with the hierarchical model.

RESULTS OF HIERARCHICAL MODELLING

Estimates of movements of tagged fish between branches

As noted in previous assessments (Chaput 2010), there is movement of tagged fish between the Northwest and Southwest Miramichi branches. About 94% of small salmon and large salmon tagged in the Southwest Miramichi at the Millerton trapnet were estimated to have stayed in the Southwest Miramichi (Table 6). The majority, 83% for small salmon and 88% for large salmon, of salmon tagged at the lower trapnets in the Southwest Miramichi are estimated to remain in the Southwest Miramichi (Table 6). The majority of small salmon tagged at the Northwest Miramichi trapnet at Cassilis remained in the Northwest Miramichi (84%; Table 6) but an important percentage of the large salmon tagged from the Northwest Miramichi Cassilis trapnet moved to the Southwest Miramichi, ranging from 24% to 46% (median values) between 1998 and 2011 (Table 6). The reason for the higher movement rate of large salmon from the Northwest is unknown.

Estimates of trapnet efficiencies

The Southwest Miramichi Millerton trapnet was estimated to have captured about 3% of the large salmon run of the Southwest Miramichi in 2011 (95% B.C.I. 1% to 4%) (Table 7). The median values over the period 1998 to 2011 have ranged from 3% to 10%. Over all years, the percentage of the run intercepted has a median value of 5% and a 95% B.C.I, of 1% to 11% (Table 7). The efficiency in 2011 for small salmon is almost twice the value of large salmon, about 6% (95% B.C.I. 4% to 9%) with median values during 1998 to 2011 of 6% to 12%. Overall, the percentage of the run of small salmon to the Southwest Miramichi captured at the Millerton trapnet has a median value of 9%, with a 95% B.C.I. of 4% to 16% (Table 7).

The Cassilis trapnet in the Northwest Miramichi captures a higher percentage of the run of small salmon and large salmon than the Millerton trapnet in the Southwest Miramichi. In 2011, 9% of the large salmon run in the Northwest Miramichi was captured at Cassilis (95% B.C.I. 5% to 15%), a similar rate to that of small salmon (median 9%; 95% B.C.I. 6% to 12%) (Table 7). Overall, the Cassilis trapnet captures about 11% of the small salmon run to the Northwest Miramichi (6% to 17%) and 10% of the large salmon run (4% to 23%).

Estimates of proportions of returns going to headwater barriers

As indicated previously, the barriers in the Northwest Miramichi and at Dungarvon in the Southwest Miramichi are considered indices of the early runs (prior to August 1) to each branch.

Based on the estimated abundances of early run fish to each branch, the counts of the Northwest Miramichi barrier represent important proportions of the early run of both the small salmon and large salmon (Table 8). For small salmon, the median values ranged from 7% to 26% of the annual early run returns and the overall percentage is estimated at 13% but it is highly variable among years (95% B.C.I. 3% to 34%) (Table 8). For large salmon, the median values range from 8% to 37% of the annual early run returns and the overall percentage is estimated at 18% but is it also highly variable annually (95% B.C.I. 4% to 45%) (Table 8).

Large salmon counts at the Dungarvon Barrier represented 1% to 6% of the annual early run return of large salmon and the overall percentage is estimated at 3% with a 95% B.C.I. range of 1% to 7% (Table 8). Small salmon have represented between 2% and 12% of the annual early run return with the overall percentage of 4% (95% B.C.I. range of 1% to 11%) (Table 8).

The Juniper barrier in the upper Southwest Miramichi is considered an index of the total run to the Southwest Miramichi. Over the period 1998 to 2009, the counts of small salmon have represented between 3% and 6% of the annual returns and the overall percentage is estimated at 4% (95% B.C.I. range of 2% to 8%) (Table 8). For large salmon, the percentage of the total run which is estimated to migrate to the barrier has varied from 4% to 6% and the overall value is 5% (95% B.C.I. of 3% to 9%). The coefficient of variation of the proportions of the total returns counted at the Juniper barrier (12% to 24%) are lower for large salmon than at the Dungarvon barrier (15% to 29%) and the Northwest Miramichi barrier (20% to 33%) but the CVs are similar among the three headwater sites for small salmon (12% to 23% for Juniper; 13% to 23% for Dungarvon; 10% to 21% for the Northwest Miramichi).

In the absence of other information, the use of these barrier counts as indices of returns would result in estimates with large uncertainties.

Estimates of returns by size group and branch

Estimates of returns by size group for the entire season and for the early run (prior to August 1) for 1998 to 2011 are presented for the Miramichi River overall in Table 9a, for the Southwest Miramichi in Table 9b and for the Northwest Miramichi in Table 9c.

Estimated returns of small salmon to the Miramichi in 2010 were about 53,000 fish and in 2011 about 46,000, the highest returns over the period 1998 to 2011 (Table 9a; Fig. 8a). Returns of large salmon in 2010 were estimated at just under 18,000 fish and about 34,000 fish in 2011, the 2011 estimated abundance is the highest of the 1998 to 2011 time series (Table 9a; Fig. 8a). Early run returns of small salmon in 2010 and 2011 were about 38,000 fish, the highest of the 1998 to 2011 time series whereas large salmon early run returns were 12,200 in 2010 and 24,600 in 2011 (Table 9a; Fig. 8a). The early run return in 2011 was about twice the run size of 2010 and from two to four times larger than the early run returns of 1998 to 2008 (Table 8a). There has been an important change in the proportion of the total return which is in the early portion of the run, with 65% or less for small salmon prior to 2008 and at 72% to 82% early run in the past four years (Table 9a). A more important change in proportion early run has been observed for the large salmon group; proportion early was 43% or less prior to 2007, rising to 50% in 2008 and at 68% to 85% in the past four years (Table 9a). The reasons for the change in run-timing are discussed by Douglas et al. (2012).

Estimated returns of small salmon to the Southwest Miramichi were 34,000 in 2010 and 31,700 in 2011, the two highest values over the 1998 to 2011 time period (Table 9b; Fig. 8b). Large salmon returns in 2010 were estimated at about 14,000 fish, within the range of values observed during 1998 to 2009 while returns in 2011 were estimated at 27,900 fish, the highest value of the time series (Table 9b; Fig. 8b). Early run small salmon returns in 2010 and 2011 were in the range of 25,000 to 26,000 fish, respectively, nearly twice the highest values estimated in most years during 1998 to 2009 (Table 9b, Fig. 8b). Early run large salmon were just under 9,000 fish in 2010, the third highest of the time series while in 2011, large salmon returns were 20,500 fish, the highest and by more than three times the value in most previous years since 1998 (Table 9b). As for the Miramichi overall, the early run of small salmon and large salmon has become a more important proportion of the total run to the Southwest Miramichi; 78% to 82% of the small salmon run and 69% to 89% of the large salmon run in the past four years (Table 9a).

In the Northwest Miramichi, small salmon returns in 2010 were about 17,800 fish, the highest of the 1998 to 2011 period, and in 2011 returns were about 13,600 fish, the third highest of the time series (Table 9c; Fig. 8c). Early run returns of small salmon in 2010 were the highest (12,800 fish) and returns in 2011 of 11,700 fish were the third highest values since 1998 (Table 9c; Fig. 8c). The proportion early in the Northwest has been quite variable over the 1998 to 2011 time period, 0.33 to 0.86, with the proportion early being consistently high at between 0.72 and 0.86 in the past four years (Table 9c). For large salmon, the estimated return in 2010 was 3,400 fish, within the range of values from 1998 to 2009 while returns in 2011 were estimated at 5,100 fish, the second highest of the time series (Table 9c; Fig. 8c). Early run returns were estimated at 2,200 large salmon in 2010 and 3,700 large salmon in 2011, the two highest values of the time series (Table 9c; Fig. 8c). The early-run estimate for 2011 is higher than the estimated total return to the Northwest Miramichi in 10 of the 14 years (Table 9c; Fig. 8c). As for the small salmon, the proportion early run for large salmon has been highly variable, from 0.17 to 0.66 during 1998 to 2007 but has been between 0.64 and 0.75 in the past four years (Table 9c).

As a prior assumption of expected run size to each branch, one could consider the relative habitat areas (or conservation egg requirements) of the Southwest Miramichi and the Northwest Miramichi rivers (Appendix 1). The conservation egg requirement for the Southwest Miramichi is 88.1 million eggs, and for the Northwest Miramichi 40.3 million eggs. The Southwest Miramichi is therefore about twice the size of the Northwest Miramichi so the expected proportion of total run to the Miramichi River which would be to the Southwest Miramichi is 0.686. The proportion of the total Miramichi River small salmon returns which were estimated for the Southwest Miramichi have been equally often above and below this a priori value (Fig. 9). In contrast, the large salmon returns to the Southwest Miramichi were estimated to have comprised a higher proportion of the total in all years, except 2001, than would be expected based on river size alone (Fig. 9). The a priori value for the expected proportion of returns to each branch is based on the assumption that the salmon in each branch have similar characteristics and population dynamics, i.e. similar proportions sea age at maturity, similar sex ratio by size group, similar river age characteristics, and similar rates of egg depositions. Several of these including river age at smoltification, sex ratio especially in the small salmon, and achieved egg depositions are known to differ between the two branches. Proportion of conservation egg requirements achieved in the two branches is a better indicator of relative performance.

RECOMMENDATIONS FOR FURTHER WORK

A few of the recommendations described in Chaput (2010) to improve the hierarchical model were implemented in this assessment. One of the recommendations was to treat the headwater barrier data as an index of early run size and in particular as an index of escapement rather than returns. This was only partially considered. In the absence of harvest data from the recreational fishery and incomplete data from the aboriginal fisheries, it is not possible to estimate escapement. In the absence of angling data post 1997, the exploitation rates and harvests would have to be estimated from the historical data and applied to the years when the angling data are unavailable. Consequently, the barrier counts were treated as an index of returns which assumes that the removals were a constant proportion of the returns over all years.

Another recommendation was to treat the angling data from the Northwest Miramichi crown reserve as an indicator of early-run size. The time series is complete back to 1984 when catch and release measures for large salmon were introduced. It is feasible to estimate the catch rates from the Crown Reserve angling stretches using the estimates of annual catch and effort and estimates of total early run returns. This would be of benefit for the years prior to 1998 when the mark and recapture program was developing in each branch and for the years prior to 1992 when the monitoring program was focused on one trapnet in the lower portion of the Miramichi. Catch rates, expressed as proportion crown reserve angling catches of the total early run estimate to the Northwest Miramichi, have varied from 0.07 to 0.43 for small salmon, 0.03 to 0.23 for large salmon, over the period 1998 to 2011. This addition to the model will be attempted at a later time.

Finally, it was recommended that the historical time series for the Miramichi be re-analyzed using the hierarchical model. The time series from 1984 to the present could be examined first as it represents the years post commercial fishery closure. Angling data from the two branches could also be used for the years when they are available (1984 to 1995, 1997). The model should incorporate the information on effort to estimate exploitation rates. Preliminary analyses of this were attempted but further work including diagnostics is required.

ACKNOWLEDGEMENTS

The field operations and data management which are the foundation of this assessment were contributed by staff from DFO Science program in the Miramichi River (in alphabetical order): John Hayward, Dave Moore and Joe Sheasgreen. Workers from Eel Ground First Nation operated the trapnet and tagged fish from the lower trapnets in the Southwest Miramichi. Workers from Metepanagiag (Red Bank) First Nation operated and sampled fish from the upper trapnets in the Northwest Miramichi. A large number of students over the years, generously supported by the Northumberland Salmon Protection Association, assisted in the summer field operations and field support in the fall was provided on contract by the Miramichi Salmon Association.

REFERENCES

Bousfield, E.L. 1955. Some physical features of the Miramichi estuary. J. Fish. Res. Bd. Canada, 12: 342-361.

Chaput, G. 2010. Assessment of Atlantic salmon (*Salmo salar*) to the Miramichi River (NB) for 1998 to 2009. DFO Can. Sci. Advis. Sec. Res. Doc. 2010/092. iv + 70 p.

Chaput, G., Moore, D., Hayward, J., Shaesgreen, J., and Dubee, B. 2000. Stock status of Atlantic salmon (*Salmo salar*) in the Miramichi River, 1999. DFO Can. Stock Assess. Secr. Res. Doc. 2000/004.

Chaput, G., Moore, D., Hayward, J., Sheasgreen, J., and Dubee, B. 2001. Stock status of Atlantic salmon (*Salmo salar*) in the Miramichi River, 2000. Can. Sci. Advi. Sec. Res. Doc. 2001/008.

DFO. 2010. Assessment of Atlantic salmon in the Miramichi River (NB), 1998 to 2009. DFO Can. Sci. Advis. Sec. Sci. Resp. 2010/005.

Hayward, J. 2001. Weekly fish counts from in-river traps, counting fences and barrier pools from the Miramichi River, 1994 to 2000. Canadian Data Report of Fisheries and Aquatic Sciences, 1080: x + 104 pp.

Madden, G.A., Cronin, P.J., Dubee, B.L., Seymour, P.D., and LeBlanc, E.J. 1999. Using artificial barriers to protect and enhance Atlantic salmon. NB Dept. of Natural Resources Management Report 99-01-E.

Moore, D.S., Chaput, G., and Pickard, R. 1995. The effect of fisheries on the biological characteristics and survival of mature Atlantic salmon (*Salmo salar*) from the Miramichi River. In E.M.P. Chadwick [ed.] Water, science, and the public: the Miramichi ecosystem. Can. Spec. Publ. Fish. Aquat. Sci. No. 123.

Randall, R.G., Moore, D.M., and Pickard, P.R. 1990. Status of Atlantic salmon in the Miramichi River during 1989. CAFSAC Res. Doc. 90/4.

Rivot, E., and Prévost, E. 2002. Hierarchical Bayesian analysis of capture–mark–recapture data. Can. J. Fish. Aquat. Sci. 59: 1768–1784.

Saunders, R.L. 1967. Seasonal pattern of return of Atlantic salmon in the Northwest Miramichi River, New Brunswick. J. Fish. Res. Bd. Canada 24: 21-32.

Saunders, R.L. 1981. Atlantic salmon (*Salmo salar*) stocks and management implications in the Canadian Atlantic Provinces and New England, USA. Can. J. Fish. Aquat. Sci. 38: 1612-1625.

Spiegelhalter, D., A. Thomas, N. Best, and D. Lunn. 2010. OpenBUGS User Manual Version 3.1.2 September 2010. http://www.mrc-bsu.cam.ac.uk/bugs.

Table 1. Counts of small salmon and large salmon at the three headwater protection barriers of the Miramichi River, 1984 to 2011.

	Large salmon			Small salmon		
Year	Northwest	Dungarvon	Juniper	Northwest	Dungarvon	Juniper
1984		93	297		315	230
1985		162	604		536	492
1986		174	1,138		501	2072
1987		202	1,266		744	1,175
1988	234	277	929	1,614	851	1,092
1989	287	315	731	966	579	969
1990	331	318	994	1,318	562	1,646
1991	224	204	476	765	296	495
1992	219	232	1,047	1,165	825	1,383
1993	216	223	1,145	1,034	659	1,349
1994	228	155	905	673	358	1,195
1995	252	95	1,019	548	329	811
1996	218	184	819	602	590	1,388
1997	152	115	519	501	391	566
1998	289	163	698	1,038	592	981
1999	387	185	698	708	378	566
2000	217	130	725	456	372	1,202
2001	202	111	904	344	295	729
2002	121	107	546	595	287	1,371
2003	186	158	920	478	389	912
2004	167	185	764	723	559	1,368
2005	262	300	673	735	441	853
2006	214	217	*829*	469	468	*860*
2007	166	88	783	460	195	945
2008	164	131	692	1,094	673	1,083
2009	206	234	889	315	207	242
2010	284	228	563	852	660	307
2011	298	327	378	995	711	267

Table 2. Capture, mark and recapture data for small salmon, 1998 to 2011.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Fish tagged														
NW Cassilis (NMid)	745	794	1076	734	1127	594	1115	783	646	828	677	255	1282	840
SW Eelground (SLow)	508	790	1065	613	625	499	524	109	175	89	78	38	452	258
SW Millerton (SMid)	1148	898	1434	1140	1587	1320	2138	1518	1948	1054	966	681	1207	1208
Tag recaptures														
RSLowSMid	39	41	55	51	49	42	34	15	12	3	3	4	20	10
RSLowNMid	6	11	22	13	13	3	11	1	3	1	0	1	3	4
RSLowNHigh	4	20	28	7	10	3	10	NA	0	0	0	0	8	2
RSMidNMid	9	4	10	8	10	16	19	10	27	9	1	1	9	3
RSMidNHigh	1	3	2	7	17	4	5	NA	1	3	2	1	3	2
RNMidSMid	9	7	12	19	20	6	13	13	9	4	6	0	21	6
RNMidNHigh	18	95	140	52	46	22	73	NA	10	59	12	8	72	12
First time catch at trapnets														
FTSMid (Millerton)	1158	924	1442	2153	2718	2182	2910	2447	2636	1353	1485	949	2591	2000
FTNMid (Cassilis)	758	835	1090	893	1664	617	1232	932	659	893	704	270	2474	1170
FTNHigh (Redbank)	246	1329	2018	763	897	275	1052	NA	72	432	105	91	1196	383
Counts at barriers														
Dungarvon	592	378	372	295	287	389	559	441	468	195	664	207	660	711
NWMiramichi	1038	708	456	344	595	478	723	735	469	460	1094	315	852	995
Juniper	981	566	1202	729	1371	912	1368	853	853	945	1087	242	307	267
Crown Reserve Catches														
Catch (kept and released)	1044	514	949	555	836	650	569	598	767	586	1685	445	1077	1520
Effort (rod days)	2488	2177	2619	2298	2566	2601	2565	2637	2579	2574	2558	2755	2208	2336
First time catches by season at DFO index trapnets (E is <= July 31; L is > July 31)														
SWMillE (Millerton)	354	493	679	1128	1533	1042	1566	1174	1426	838	1143	749	1860	1615
SWMillL (Millerton)	804	431	763	1025	1185	1140	1344	1273	1210	515	342	200	731	385
NWCassE (Cassilis)	442	662	610	305	1364	347	658	417	204	579	559	205	1764	1005
NWCassL (Cassilis)	316	173	480	588	300	270	574	515	455	314	145	65	710	165

Table 3. Capture, mark and recapture data for large salmon, 1998 to 2011.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Fish tagged														
NW Cassilis (NMid)	210	274	275	946	182	335	351	387	206	347	121	197	443	399
SW Eelground (SLow)	309	357	355	704	231	345	338	190	210	279	118	440	440	417
SW Millerton (SMid)	354	403	382	1271	494	1050	972	705	1005	581	281	537	621	644
Tag recaptures														
RSLowSMid	5	15	9	57	12	17	13	11	10	1	1	19	17	7
RSLowNMid	1	1	9	20	1	2	7	4	3	6	0	6	5	1
RSLowNHigh	1	13	5	7	1	0	2	NA	0	0	0	1	2	1
RSMidNMid	1	0	2	12	5	10	9	8	7	2	1	1	1	7
RSMidNHigh	0	1	1	4	4	5	2	NA	0	1	0	2	1	0
RNMidSMid	2	2	3	35	0	9	4	2	4	12	3	0	14	3
RNMidNHigh	4	27	20	33	13	18	20	NA	0	14	1	5	30	9
First time catch at trapnets														
FTSMid (Millerton)	363	436	395	1352	510	1080	1040	750	1047	613	298	824	798	732
FTNMid (Cassilis)	217	280	277	983	188	339	358	417	210	365	124	204	524	464
FTNHigh (Redbank)	64	551	610	517	140	146	261	NA	11	205	15	80	333	252
Counts at barriers														
Dungarvon	163	185	130	111	107	158	185	300	217	88	131	234	228	327
NWMiramichi	289	387	217	202	121	186	167	262	214	166	164	207	284	298
Juniper	698	698	725	904	546	920	764	673	829	783	692	889	563	378
Crown Reserve Catches														
Catch (kept and released)	125	68	93	119	66	174	74	112	99	125	135	235	158	274
Effort (rod days)	2488	2177	2619	2298	2566	2601	2565	2637	2579	2574	2558	2755	2208	2336
First time catches by season at DFO index trapnets (E is <= July 31; L is > July 31)														
SWMillE (Millerton)	119	171	124	432	172	377	378	264	342	299	205	715	550	529
SWMillL (Millerton)	244	265	271	920	338	703	662	486	705	314	93	109	248	203
NWCassE (Cassilis)	73	155	85	179	120	104	124	119	29	201	79	148	333	330
NWCassL (Cassilis)	144	125	192	804	68	235	234	298	181	164	45	56	191	134

Table 4a. Miramichi River: retrospective analysis of model results based on consistent model structure and data inputs as per hierarchical model describe in Chaput (2010) for which the headwater barrier counts are considered as indices of total run for the year.

Miramichi small salmon									
	2009 Assessment			2010 Assessment			2011 Assessment		
Year	Median	95% BCI		Median	95% BCI		Median	95% BCI	
1998	22,810	19,070	27,920	22,360	18,770	27,060	22,760	18,840	28,120
1999	22,380	19,390	26,270	22,610	19,590	26,620	23,100	20,010	27,280
2000	32,860	28,620	38,180	32,670	28,770	37,850	32,960	28,870	38,420
2001	27,120	23,290	32,190	27,820	23,810	33,330	27,570	23,350	32,870
2002	41,250	35,610	48,470	41,510	35,690	48,330	41,410	35,310	49,150
2003	27,760	22,960	33,640	28,590	23,650	35,010	28,600	23,440	35,060
2004	44,290	37,340	53,260	45,490	38,460	56,330	45,870	38,530	56,250
2005	29,230	22,920	38,480	30,680	23,390	40,700	30,540	23,410	41,170
2006	30,570	23,850	39,930	33,540	26,200	43,980	33,380	25,390	44,650
2007	24,770	19,300	34,900	25,340	19,390	37,440	25,540	18,460	39,800
2008	29,840	22,540	40,340	30,260	22,620	45,350	31,970	23,590	48,950
2009	11,620	8,230	17,230	13,400	9,721	19,550	13,780	9,968	19,740
2010				50,500	42,920	61,370	51,940	43,460	63,050
2011							45,870	35,540	61,990

Miramichi large salmon									
	2009 Assessment			2010 Assessment			2011 Assessment		
Year	Median	95% BCI		Median	95% BCI		Median	95% BCI	
1998	16,280	12120	21620	16,270	12470	21650	16,940	12,190	24,820
1999	15,890	12530	19750	15,920	12540	19870	15,740	12,190	21,210
2000	16,750	13030	21220	16,830	13140	21660	16,130	12,560	22,200
2001	22,340	19330	25780	22,310	19330	25800	21,830	18,930	25,560
2002	11,430	8909	15350	11,690	9096	15230	12,060	9,046	17,450
2003	19,160	15650	24770	19,570	15660	24930	19,930	15,520	26,550
2004	19,870	15710	27190	20,300	16250	26970	22,950	17,750	31,210
2005	17,690	13520	25140	17,990	13680	24900	20,720	14,860	29,460
2006	18,760	14630	25730	19,380	15190	26150	21,100	16,010	30,160
2007	17,240	13580	22540	17,410	13590	22900	17,380	13,220	23,970
2008	13,290	9454	18640	13,480	9615	18620	12,910	8,819	19,510
2009	19,100	15330	24950	19,710	15280	25690	20,720	15,630	28,210
2010				17,090	13970	21800	18,770	14,950	23,850
2011							29,330	21,430	42,350

Table 4b. Southwest Miramichi retrospective analysis of model results based on consistent model structure and data inputs as per hierarchical model describe in Chaput (2010) for which the headwater barrier counts are considered as indices of total run for the year.

Southwest Miramichi small salmon									
	2009 Assessment			2010 Assessment			2011 Assessment		
Year	Median	95% BCI		Median	95% BCI		Median	95% BCI	
1998	14,480	11,140	19,100	14,050	10,880	18,400	14,230	10810	18960
1999	12,830	10,160	16,590	13,210	10,420	17,070	13,480	10540	17680
2000	20,100	15,890	25,540	20,030	16,000	25,360	20,200	16090	25870
2001	18,370	14,710	23,710	19,410	15,360	25,060	19,000	14890	24460
2002	25,460	20,190	32,480	26,070	20,730	33,080	26,000	20340	33660
2003	21,130	16,490	27,020	22,250	17,320	28,580	22,140	16970	28720
2004	31,620	24,770	40,710	33,100	26,090	44,100	33,460	26080	44180
2005	19,580	14,390	28,040	21,370	14,980	30,210	21,030	14820	30250
2006	24,910	18,250	34,560	28,190	21,070	38,640	28,060	20240	39360
2007	18,310	13,040	28,540	19,070	13,350	31,270	19,390	12390	33930
2008	22,370	15,700	32,670	22,800	15,690	37,440	24,290	16220	41290
2009	8,762	5,611	14,280	10,560	7,001	16,670	10,850	7132	16900
2010				31,950	24,760	43,070	33,270	25320	44620
2011							30,790	21680	46630

Southwest Miramichi large salmon									
	2009 Assessment			2010 Assessment			2011 Assessment		
Year	Median	95% BCI		Median	95% BCI		Median	95% BCI	
1998	12,490	8,815	17,890	12,840	9,284	18,380	13,660	9189	21580
1999	11,280	8,051	15,020	11,620	8,374	15,630	11,580	8121	17010
2000	11,900	8,305	16,350	12,310	8,676	17,060	11,760	8242	17830
2001	13,940	10,670	17,580	14,440	11,440	18,160	13,850	10920	17850
2002	9,402	6,876	13,280	9,752	7,242	13,250	10,200	7160	15660
2003	16,100	12,520	21,710	16,690	12,730	22,100	17,140	12660	23720
2004	16,100	11,930	23,390	16,720	12,630	23,520	19,530	14230	27890
2005	13,630	9,795	20,910	14,230	10,290	21,090	17,030	11440	25740
2006	15,880	11,850	22,680	16,750	12,650	23,480	18,560	13500	27770
2007	13,530	9,909	18,810	13,910	10,050	19,340	13,870	9763	20860
2008	11,210	7,583	16,280	11,540	7,729	16,650	11,020	7122	17650
2009	16,060	12,320	21,940	16,890	12,540	22,860	18,040	12980	25480
2010				12,720	9,676	17,360	14,510	10630	19650
2011							23,470	15510	36500

Table 4c. Northwest Miramichi retrospective analysis of model results based on consistent model structure and data inputs as per hierarchical model describe in Chaput (2010) for which the headwater barrier counts are considered as indices of total run for the year.

Northwest Miramichi small salmon									
	2009 Assessment			2010 Assessment			2011 Assessment		
Year	Median	95% BCI		Median	95% BCI		Median	95% BCI	
1998	7,541	5,813	10,310	7,521	5,702	10,460	7,783	5946	10690
1999	8,621	7,158	10,570	8,498	7,091	10,220	8,679	7228	10520
2000	11,520	9,886	13,610	11,450	9,738	13,530	11,500	9683	13640
2001	7,893	6,210	9,939	7,589	6,051	9,532	7,688	6130	9619
2002	14,760	11,970	18,330	14,340	11,510	18,260	14,380	11520	18070
2003	5,883	4,494	7,788	5,667	4,233	7,671	5,736	4287	7810
2004	11,770	9,746	14,350	11,510	9,480	13,990	11,560	9599	14190
2005	8,940	6,231	14,630	8,744	6,163	13,240	8,936	6064	14390
2006	5,167	3,528	7,187	4,867	3,414	6,751	4,849	3353	6930
2007	6,189	4,755	8,081	5,905	4,530	7,606	5,867	4589	7532
2008	7,013	5,093	10,760	7,094	5,018	10,790	7,295	5105	10700
2009	2,668	1,899	4,081	2,647	1,850	4,069	2,739	1906	4174
2010				17,630	14,040	22,120	17,670	14110	22650
2011							14,270	10350	20700

Northwest Miramichi large salmon									
	2009 Assessment			2010 Assessment			2011 Assessment		
Year	Median	95% BCI		Median	95% BCI		Median	95% BCI	
1998	3,212	1,821	6,036	2,881	1,723	5,102	2,774	1625	5073
1999	4,100	2,840	6,122	3,792	2,650	5,452	3,691	2543	5314
2000	4,322	2,840	6,526	4,015	2,571	6,091	3,891	2584	5705
2001	7,220	5,130	10,210	6,744	4,464	9,459	6,790	4616	9587
2002	1,732	1,138	2,628	1,609	1,074	2,426	1,545	1033	2312
2003	2,520	1,681	3,799	2,346	1,559	3,531	2,280	1507	3364
2004	3,252	2,295	4,674	3,034	2,066	4,428	2,892	1993	4214
2005	3,600	2,223	5,980	3,322	2,002	5,687	3,252	1928	5274
2006	2,437	1,426	4,235	2,197	1,350	3,863	2,104	1224	3583
2007	3,230	2,051	4,984	2,985	1,905	4,746	2,957	1902	4563
2008	1,799	1,007	3,776	1,638	912.5	3,364	1,583	885	3081
2009	2,507	1,554	4,106	2,293	1,430	3,735	2,181	1359	3535
2010				3,751	2,575	5,350	3,630	2521	5168
2011							5,152	3397	8197

Table 5a. Estimated returns to the Miramichi River by size group based on variations in model structure and data inputs.

Miramichi small salmon						
	2009 Version			2011 Version		
Year	Median	95% BCI		Median	95% BCI	
1998	22,760	18,840	28,120	23,680	19,540	28,990
1999	23,100	20,010	27,280	22,430	19,500	26,420
2000	32,960	28,870	38,420	33,480	29,200	39,120
2001	27,570	23,350	32,870	27,470	23,520	32,250
2002	41,410	35,310	49,150	41,790	36,300	49,180
2003	28,600	23,440	35,060	28,260	23,680	34,450
2004	45,870	38,530	56,250	45,480	37,750	55,210
2005	30,540	23,410	41,170	30,550	23,980	39,560
2006	33,380	25,390	44,650	32,190	25,260	41,840
2007	25,540	18,460	39,800	26,000	20,050	35,480
2008	31,970	23,590	48,950	28,760	22,030	39,230
2009	13,780	9,968	19,740	11,520	8,374	17,060
2010	51,940	43,460	63,050	52,730	43,550	65,950
2011	45,870	35,540	61,990	45,880	35,750	59,390

Miramichi large salmon						
	2009 Version			2011 Version		
Year	Median	95% BCI		Median	95% BCI	
1998	16,940	12,190	24,820	17,060	12,790	23,480
1999	15,740	12,190	21,210	15,750	12,210	20,230
2000	16,130	12,560	22,200	17,410	13,710	22,330
2001	21,830	18,930	25,560	22,700	19,590	26,270
2002	12,060	9,046	17,450	12,090	9,308	16,050
2003	19,930	15,520	26,550	20,210	16,270	26,120
2004	22,950	17,750	31,210	21,370	16,720	30,350
2005	20,720	14,860	29,460	18,860	14,410	26,460
2006	21,100	16,010	30,160	21,430	16,420	29,850
2007	17,380	13,220	23,970	17,890	14,010	23,940
2008	12,910	8,819	19,510	13,290	8,666	18,980
2009	20,720	15,630	28,210	19,070	15,360	25,500
2010	18,770	14,950	23,850	17,970	14,200	23,180
2011	29,330	21,430	42,350	34,090	23,010	63,610

<u>Version 2009</u>: trapnets and barriers, barrier counts treated as index of total return for all years
<u>Version 2011</u>: trapnets and barriers, barrier counts of NWMiramichi and SWDungarvon treated as index of early season returns (pre-Aug. 1). SWJuniper counts as index of total returns for 1998 to 2009 only (2010 and 2011 excluded)

Table 5b. Estimated returns to the Southwest Miramichi River by size group based on variations in model structure and data inputs.

Southwest Miramichi small salmon						
	2009 Version			2011 Version		
Year	Median	95% BCI		Median	95% BCI	
1998	14,230	10,810	18,960	15,260	11,590	20,410
1999	13,480	10,540	17,680	12,890	10,160	16,860
2000	20,200	16,090	25,870	20,730	16,540	26,500
2001	19,000	14,890	24,460	18,700	14,920	23,480
2002	26,000	20,340	33,660	26,370	21,150	33,120
2003	22,140	16,970	28,720	21,670	17,230	27,890
2004	33,460	26,080	44,180	32,910	25,300	42,820
2005	21,030	14,820	30,250	20,630	14,970	27,710
2006	28,060	20,240	39,360	26,100	19,500	35,870
2007	19,390	12,390	33,930	19,720	13,820	29,160
2008	24,290	16,220	41,290	21,740	15,400	32,200
2009	10,850	7,132	16,900	8,712	5,837	14,470
2010	33,270	25,320	44,620	34,010	25,300	47,500
2011	30,790	21,680	46,630	31,710	22,360	45,890

Southwest Miramichi large salmon						
	2009 Version			2011 Version		
Year	Median	95% BCI		Median	95% BCI	
1998	13,660	9,189	21,580	13,370	9,519	19,800
1999	11,580	8,121	17,010	11,680	8,249	16,190
2000	11,760	8,242	17,830	12,610	8,926	17,550
2001	13,850	10,920	17,850	14,220	11,120	17,910
2002	10,200	7,160	15,660	10,260	7,486	14,300
2003	17,140	12,660	23,720	17,250	13,300	23,240
2004	19,530	14,230	27,890	17,790	13,090	26,930
2005	17,030	11,440	25,740	14,570	10,600	22,120
2006	18,560	13,500	27,770	17,270	12,750	25,760
2007	13,870	9,763	20,860	14,470	10,560	20,560
2008	11,020	7,122	17,650	11,580	6,998	17,350
2009	18,040	12,980	25,480	16,530	12,850	23,020
2010	14,510	10,630	19,650	13,850	10,210	19,230
2011	23,470	15,510	36,500	27,870	17,140	58,150

Version 2009: trapnets and barriers, barrier counts treated as index of total return for all years
Version 2011: trapnets and barriers, barrier counts of NWMiramichi and SWDungarvon treated as index of early season returns (pre-Aug. 1). SWJuniper counts as index of total returns for 1998 to 2009 only (2010 and 2011 excluded)

Table 5c. Estimated returns to the Northwest Miramichi River by size group based on variations in model structure and data inputs.

Northwest Miramichi small salmon						
	2009 Version			2011 Version		
Year	Median	95% BCI		Median	95% BCI	
1998	7,783	5,946	10,690	7,605	5,834	10,430
1999	8,679	7,228	10,520	8,613	7,164	10,530
2000	11,500	9,683	13,640	11,530	9,734	13,550
2001	7,688	6,130	9,619	7,925	6,361	9,922
2002	14,380	11,520	18,070	14,500	11,590	18,110
2003	5,736	4,287	7,810	5,844	4,456	7,874
2004	11,560	9,599	14,190	11,720	9,590	14,430
2005	8,936	6,064	14,390	9,425	6,441	14,970
2006	4,849	3,353	6,930	5,474	3,885	7,802
2007	5,867	4,589	7,532	6,029	4,645	7,699
2008	7,295	5,105	10,700	6,626	4,856	9,685
2009	2,739	1,906	4,174	2,602	1,834	3,949
2010	17,670	14,110	22,650	17,830	14,020	22,300
2011	14,270	10,350	20,700	13,550	9,976	18,680

Northwest Miramichi large salmon						
	2009 Version			2011 Version		
Year	Median	95% BCI		Median	95% BCI	
1998	2,774	1,625	5,073	3,070	1,760	5,935
1999	3,691	2,543	5,314	3,584	2,470	5,214
2000	3,891	2,584	5,705	4,259	2,774	6,482
2001	6,790	4,616	9,587	7,297	5,135	10,180
2002	1,545	1,033	2,312	1,503	969	2,347
2003	2,280	1,507	3,364	2,403	1,573	3,648
2004	2,892	1,993	4,214	3,092	2,095	4,523
2005	3,252	1,928	5,274	3,732	2,180	6,698
2006	2,104	1,224	3,583	3,472	1,959	7,055
2007	2,957	1,902	4,563	2,941	1,818	4,629
2008	1,583	885	3,081	1,401	780	2,855
2009	2,181	1,359	3,535	1,998	1,231	3,230
2010	3,630	2,521	5,168	3,444	2,345	5,073
2011	5,152	3,397	8,197	5,147	3,180	8,813

Version 2009: trapnets and barriers, barrier counts treated as index of total return for all years
Version 2011: trapnets and barriers, barrier counts of NWMiramichi and SWDungarvon treated as index of early season returns (pre-Aug. 1). SWJuniper counts as index of total returns for 1998 to 2009 only (2010 and 2011 excluded)

Table 6. Proportion of tagged fish staying in the branch in which they were marked, 1998 to 2011.

Northwest Miramichi (Cassilis						
	Small salmon			Large salmon		
Year	Median	95% BCI		Median	95% BCI	
1998	0.84	0.74	0.90	0.67	0.44	0.87
1999	0.85	0.77	0.92	0.69	0.50	0.89
2000	0.83	0.75	0.89	0.62	0.39	0.82
2001	0.80	0.70	0.87	0.58	0.42	0.71
2002	0.82	0.73	0.88	0.76	0.55	0.96
2003	0.86	0.78	0.93	0.66	0.49	0.80
2004	0.85	0.77	0.90	0.72	0.53	0.88
2005	0.84	0.76	0.91	0.76	0.54	0.93
2006	0.85	0.77	0.91	0.64	0.39	0.83
2007	0.88	0.81	0.95	0.54	0.34	0.71
2008	0.85	0.77	0.92	0.60	0.31	0.80
2009	0.88	0.80	0.97	0.75	0.52	0.96
2010	0.81	0.72	0.87	0.62	0.45	0.75
2011	0.85	0.75	0.92	0.63	0.38	0.83
Overall	0.84	0.71	0.94	0.66	0.35	0.91

Table 6 (continued). Proportion of tagged fish staying in the branch in which they were marked, 1998 to 2011.

Southwest Miramichi (Lower Enclosure trapnets)						
	Small salmon			Large salmon		
Year	Median	95% BCI		Median	95% BCI	
1998	0.84	0.77	0.91	0.89	0.76	0.97
1999	0.83	0.76	0.88	0.84	0.73	0.91
2000	0.82	0.76	0.86	0.82	0.69	0.90
2001	0.83	0.76	0.88	0.82	0.72	0.89
2002	0.81	0.72	0.86	0.92	0.83	0.98
2003	0.86	0.79	0.93	0.94	0.85	0.98
2004	0.81	0.72	0.87	0.86	0.74	0.93
2005	0.84	0.76	0.93	0.86	0.71	0.94
2006	0.83	0.74	0.91	0.85	0.66	0.94
2007	0.84	0.76	0.93	0.86	0.71	0.94
2008	0.84	0.75	0.94	0.91	0.76	0.99
2009	0.83	0.72	0.91	0.88	0.77	0.94
2010	0.84	0.77	0.90	0.91	0.83	0.96
2011	0.82	0.70	0.89	0.93	0.83	0.98
Overall	0.83	0.71	0.92	0.88	0.67	0.98

Southwest Miramichi (Millerton)						
	Small salmon			Large salmon		
Year	Median	95% BCI		Median	95% BCI	
1998	0.93	0.88	0.96	0.95	0.87	0.99
1999	0.96	0.92	0.98	0.97	0.92	0.99
2000	0.96	0.93	0.98	0.95	0.89	0.98
2001	0.93	0.89	0.96	0.93	0.89	0.96
2002	0.90	0.86	0.94	0.92	0.85	0.96
2003	0.90	0.85	0.94	0.93	0.87	0.96
2004	0.94	0.90	0.96	0.94	0.89	0.97
2005	0.93	0.88	0.96	0.91	0.81	0.96
2006	0.90	0.83	0.93	0.91	0.80	0.96
2007	0.94	0.90	0.97	0.96	0.91	0.99
2008	0.96	0.91	0.98	0.95	0.87	0.99
2009	0.96	0.91	0.99	0.95	0.89	0.98
2010	0.94	0.91	0.97	0.97	0.93	0.99
2011	0.95	0.91	0.98	0.93	0.85	0.96
Overall	0.94	0.84	0.98	0.94	0.82	0.99

Table 7. Proportion of run intercepted by the Northwest Cassilis and SW Millerton trapnets, 1998 to 2011.

Northwest Miramichi (Cassilis)						
	Small salmon			Large salmon		
Year	Median	95% BCI		Median	95% BCI	
1998	0.10	0.07	0.13	0.07	0.04	0.12
1999	0.10	0.08	0.12	0.08	0.05	0.11
2000	0.10	0.08	0.11	0.07	0.04	0.10
2001	0.11	0.09	0.14	0.14	0.10	0.19
2002	0.11	0.09	0.14	0.12	0.08	0.19
2003	0.11	0.08	0.14	0.14	0.09	0.21
2004	0.11	0.09	0.13	0.12	0.08	0.17
2005	0.10	0.06	0.14	0.11	0.06	0.19
2006	0.12	0.08	0.17	0.06	0.03	0.11
2007	0.15	0.11	0.19	0.12	0.08	0.20
2008	0.11	0.07	0.14	0.09	0.04	0.16
2009	0.10	0.07	0.15	0.10	0.06	0.17
2010	0.14	0.11	0.18	0.15	0.10	0.22
2011	0.09	0.06	0.12	0.09	0.05	0.15
Overall	0.11	0.06	0.17	0.10	0.04	0.23

Southwest Miramichi (Millerton)						
	Small salmon			Large salmon		
Year	Median	95% BCI		Median	95% BCI	
1998	0.08	0.06	0.10	0.03	0.02	0.04
1999	0.07	0.06	0.09	0.04	0.03	0.05
2000	0.07	0.05	0.09	0.03	0.02	0.04
2001	0.12	0.09	0.14	0.10	0.08	0.12
2002	0.10	0.08	0.13	0.05	0.04	0.07
2003	0.10	0.08	0.13	0.06	0.05	0.08
2004	0.09	0.07	0.11	0.06	0.04	0.08
2005	0.12	0.09	0.16	0.05	0.03	0.07
2006	0.10	0.07	0.13	0.06	0.04	0.08
2007	0.07	0.05	0.10	0.04	0.03	0.06
2008	0.07	0.05	0.10	0.03	0.02	0.04
2009	0.11	0.07	0.16	0.05	0.04	0.06
2010	0.08	0.05	0.10	0.06	0.04	0.08
2011	0.06	0.04	0.09	0.03	0.01	0.04
Overall	0.09	0.04	0.16	0.05	0.01	0.11

Table 8. Proportion of salmon run at the headwater barriers, 1998 to 2011.

Northwest Miramichi Barrier – proportion count of early run						
	Small salmon			Large salmon		
Year	Median	95% BCI		Median	95% BCI	
1998	0.23	0.17	0.30	0.27	0.14	0.47
1999	0.10	0.08	0.12	0.19	0.13	0.28
2000	0.07	0.06	0.08	0.16	0.10	0.26
2001	0.12	0.10	0.16	0.15	0.10	0.22
2002	0.05	0.04	0.06	0.12	0.08	0.20
2003	0.14	0.10	0.19	0.24	0.15	0.38
2004	0.11	0.09	0.14	0.15	0.10	0.23
2005	0.17	0.11	0.25	0.24	0.13	0.41
2006	0.26	0.18	0.37	0.37	0.19	0.65
2007	0.12	0.09	0.15	0.10	0.06	0.17
2008	0.21	0.14	0.28	0.18	0.09	0.33
2009	0.16	0.10	0.23	0.14	0.08	0.23
2010	0.07	0.05	0.09	0.13	0.09	0.19
2011	0.08	0.06	0.12	0.08	0.05	0.13
Overall	0.13	0.03	0.34	0.18	0.04	0.45

Southwest Miramichi Dungarvon Barrier – proportion count of early run						
	Small salmon			Large salmon		
Year	Median	95% BCI		Median	95% BCI	
1998	0.12	0.09	0.16	0.04	0.02	0.05
1999	0.05	0.04	0.07	0.04	0.03	0.06
2000	0.04	0.03	0.05	0.03	0.02	0.05
2001	0.03	0.02	0.04	0.02	0.02	0.03
2002	0.02	0.01	0.02	0.03	0.02	0.04
2003	0.04	0.03	0.05	0.03	0.02	0.03
2004	0.03	0.02	0.04	0.03	0.02	0.04
2005	0.04	0.03	0.06	0.06	0.04	0.08
2006	0.03	0.02	0.04	0.04	0.02	0.05
2007	0.02	0.01	0.02	0.01	0.01	0.02
2008	0.04	0.03	0.06	0.02	0.01	0.03
2009	0.03	0.02	0.05	0.02	0.01	0.02
2010	0.03	0.02	0.04	0.02	0.02	0.03
2011	0.03	0.02	0.04	0.02	0.01	0.03
Overall	0.04	0.01	0.11	0.03	0.01	0.07

Table 8 (continued). Proportion of salmon run at the headwater barriers, 1998 to 2011.

Southwest Miramichi Juniper Barrier – proportion count of total run						
	Small salmon			Large salmon		
Year	Median	95% BCI		Median	95% BCI	
1998	0.06	0.05	0.08	0.05	0.03	0.07
1999	0.04	0.03	0.05	0.06	0.04	0.08
2000	0.06	0.04	0.07	0.06	0.04	0.08
2001	0.04	0.03	0.05	0.06	0.05	0.08
2002	0.05	0.04	0.06	0.05	0.04	0.07
2003	0.04	0.03	0.05	0.05	0.04	0.07
2004	0.04	0.03	0.05	0.04	0.03	0.06
2005	0.04	0.03	0.06	0.05	0.03	0.06
2006	0.03	0.02	0.04	0.05	0.03	0.06
2007	0.05	0.03	0.07	0.05	0.04	0.07
2008	0.05	0.03	0.07	0.06	0.04	0.10
2009	0.03	0.02	0.04	0.05	0.04	0.07
2010						
2011						
Overall	0.04	0.02	0.08	0.05	0.03	0.09

Table 9a. Estimated returns (median, 95% BCI) of small salmon (upper table) and large salmon (lower table) to the Miramichi River, 1998 to 2011 based on the 2011 version of the model treating barrier counts at NWMiramichi and SWDungarvon as indicators of early run size, the SW Juniper barrier is an indicator of total run size to the Southwest Miramichi (excluding 2010 and 2011).

Miramichi River Small Salmon							
	Total run for the year			Total early run (prior to Aug. 1)			Prop. early
Year	Median	95% Bayesian Credibility Interval		Median	95% Bayesian Credibility Interval		
1998	23,680	19,540	28,990	9,483	7,885	11,540	0.40
1999	22,430	19,500	26,420	14,260	12,470	16,640	0.64
2000	33,480	29,200	39,120	16,800	14,650	19,580	0.50
2001	27,470	23,520	32,250	12,890	10,840	15,420	0.47
2002	41,790	36,300	49,180	27,370	23,840	32,020	0.65
2003	28,260	23,680	34,450	14,020	11,760	17,010	0.50
2004	45,480	37,750	55,210	24,420	20,200	29,740	0.54
2005	30,550	23,980	39,560	14,350	11,210	18,570	0.47
2006	32,190	25,260	41,840	16,080	12,410	21,340	0.50
2007	26,000	20,050	35,480	16,280	12,560	22,180	0.63
2008	28,760	22,030	39,230	22,310	17,080	30,360	0.78
2009	11,520	8,374	17,060	9,013	6,525	13,380	0.78
2010	52,730	43,550	65,950	37,760	31,160	47,250	0.72
2011	45,880	35,750	59,390	37,760	29,500	48,730	0.82

Miramichi River Large Salmon							
	Total run for the year			Total early run (prior to Aug. 1)			Prop. early
Year							
1998	17,060	12,790	23,480	5,664	4,173	7,917	0.33
1999	15,750	12,210	20,230	6,798	5,282	8,718	0.43
2000	17,410	13,710	22,330	5,421	4,172	7,098	0.31
2001	22,700	19,590	26,270	6,189	5,196	7,380	0.27
2002	12,090	9,308	16,050	4,551	3,511	5,968	0.38
2003	20,210	16,270	26,120	6,936	5,514	9,068	0.34
2004	21,370	16,720	30,350	7,699	5,950	11,040	0.36
2005	18,860	14,410	26,460	6,432	4,839	9,128	0.34
2006	21,430	16,420	29,850	6,365	4,800	9,141	0.30
2007	17,890	14,010	23,940	8,875	6,935	11,880	0.50
2008	13,290	8,666	18,980	9,019	5,860	13,020	0.68
2009	19,070	15,360	25,500	16,230	13,030	21,800	0.85
2010	17,970	14,200	23,180	12,180	9,580	15,780	0.68
2011	34,090	23,010	63,610	24,550	16,510	45,740	0.72

Table 9b. Estimated returns (median, 95% BCI) of small salmon (upper table) and large salmon (lower table) to the Southwest Miramichi River, 1998 to 2011 based on 2011 version of the model treating barrier counts at NWMiramichi and SWDungarvon as indicators of early run size, the SW Juniper barrier is an indicator of total run size to the Southwest Miramichi (excluding 2010 and 2011).

Southwest Miramichi Small Salmon							
	Total estimated return			Early run (before Aug. 1) return			
Year	Median	95% BCI		Median	95% BCI		Prop. early
1998	15,260	11,590	20,410	4,875	3,674	6,547	0.32
1999	12,890	10,160	16,860	7,252	5,736	9,418	0.56
2000	20,730	16,540	26,500	10,190	8,142	13,030	0.49
2001	18,700	14,920	23,480	10,100	8,061	12,680	0.54
2002	26,370	21,150	33,120	15,220	12,220	19,140	0.58
2003	21,670	17,230	27,890	10,570	8,397	13,610	0.49
2004	32,910	25,300	42,820	18,000	13,850	23,370	0.55
2005	20,630	14,970	27,710	9,996	7,250	13,440	0.48
2006	26,100	19,500	35,870	14,240	10,660	19,560	0.55
2007	19,720	13,820	29,160	12,290	8,610	18,230	0.62
2008	21,740	15,400	32,200	16,850	11,930	24,980	0.78
2009	8,712	5,837	14,470	6,913	4,632	11,490	0.79
2010	34,010	25,300	47,500	24,820	18,520	34,630	0.73
2011	31,710	22,360	45,890	25,860	18,260	37,260	0.82

Southwest Miramichi Large Salmon							
	Total estimated return			Early run (before Aug. 1) return			
Year	Median	95% BCI		Median	95% BCI		Prop. early
1998	13,370	9,519	19,800	4,503	3,168	6,762	0.34
1999	11,680	8,249	16,190	4,729	3,334	6,628	0.40
2000	12,610	8,926	17,550	4,064	2,836	5,748	0.32
2001	14,220	11,120	17,910	4,813	3,745	6,094	0.34
2002	10,260	7,486	14,300	3,530	2,539	4,964	0.34
2003	17,250	13,300	23,240	6,145	4,715	8,297	0.36
2004	17,790	13,090	26,930	6,585	4,814	9,996	0.37
2005	14,570	10,600	22,120	5,268	3,778	7,931	0.36
2006	17,270	12,750	25,760	5,740	4,213	8,538	0.33
2007	14,470	10,560	20,560	7,203	5,258	10,200	0.50
2008	11,580	6,998	17,350	8,020	4,853	12,080	0.69
2009	16,530	12,850	23,020	14,670	11,460	20,320	0.89
2010	13,850	10,210	19,230	9,899	7,349	13,640	0.71
2011	27,870	17,140	58,150	20,500	12,690	42,310	0.74

Table 9c. Estimated returns (median, 95% BCI) of small salmon (upper table) and large salmon (lower table) to the Northwest Miramichi River, 1998 to 2011, based on 2011 version of the model treating barrier counts at NWMiramichi and SWDungarvon as indicators of early run size, the SW Juniper barrier is an indicator of total run size to the Southwest Miramichi (excluding 2010 and 2011).with Crown Reserve catches.

Northwest Miramichi Small Salmon

	Total estimated return			Early run (before Aug. 1) return			
Year	Median	95% BCI		Median	95% BCI		Prop. early
1998	7,605	5,834	10,430	4,531	3,462	6,224	0.60
1999	8,613	7,164	10,530	6,947	5,762	8,522	0.81
2000	11,530	9,734	13,550	6,570	5,507	7,796	0.57
2001	7,925	6,361	9,922	2,759	2,181	3,505	0.35
2002	14,500	11,590	18,110	12,090	9,660	15,120	0.83
2003	5,844	4,456	7,874	3,385	2,558	4,587	0.58
2004	11,720	9,590	14,430	6,366	5,175	7,887	0.54
2005	9,425	6,441	14,970	4,274	2,906	6,769	0.45
2006	5,474	3,885	7,802	1,785	1,252	2,574	0.33
2007	6,029	4,645	7,699	3,950	3,037	5,060	0.66
2008	6,626	4,856	9,685	5,302	3,880	7,745	0.80
2009	2,602	1,834	3,949	2,000	1,403	3,048	0.77
2010	17,830	14,020	22,300	12,810	10,050	16,040	0.72
2011	13,550	9,976	18,680	11,720	8,635	16,140	0.86

Northwest Miramichi Large Salmon

	Total estimated return			Early run (before Aug. 1) return			
Year	Median	95% BCI		Median	95% BCI		Prop. early
1998	3,070	1,760	5,935	1,069	607	2,069	0.35
1999	3,584	2,470	5,214	2,017	1,378	2,973	0.56
2000	4,259	2,774	6,482	1,315	838	2,060	0.31
2001	7,297	5,135	10,180	1,354	928	1,932	0.19
2002	1,503	969	2,347	987	629	1,552	0.66
2003	2,403	1,573	3,648	770	493	1,191	0.32
2004	3,092	2,095	4,523	1,097	727	1,638	0.35
2005	3,732	2,180	6,698	1,098	638	1,976	0.29
2006	3,472	1,959	7,055	574	326	1,124	0.17
2007	2,941	1,818	4,629	1,642	1,008	2,607	0.56
2008	1,401	780	2,855	907	504	1,837	0.65
2009	1,998	1,231	3,230	1,498	920	2,427	0.75
2010	3,444	2,345	5,073	2,217	1,501	3,277	0.64
2011	5,147	3,180	8,813	3,702	2,280	6,340	0.72

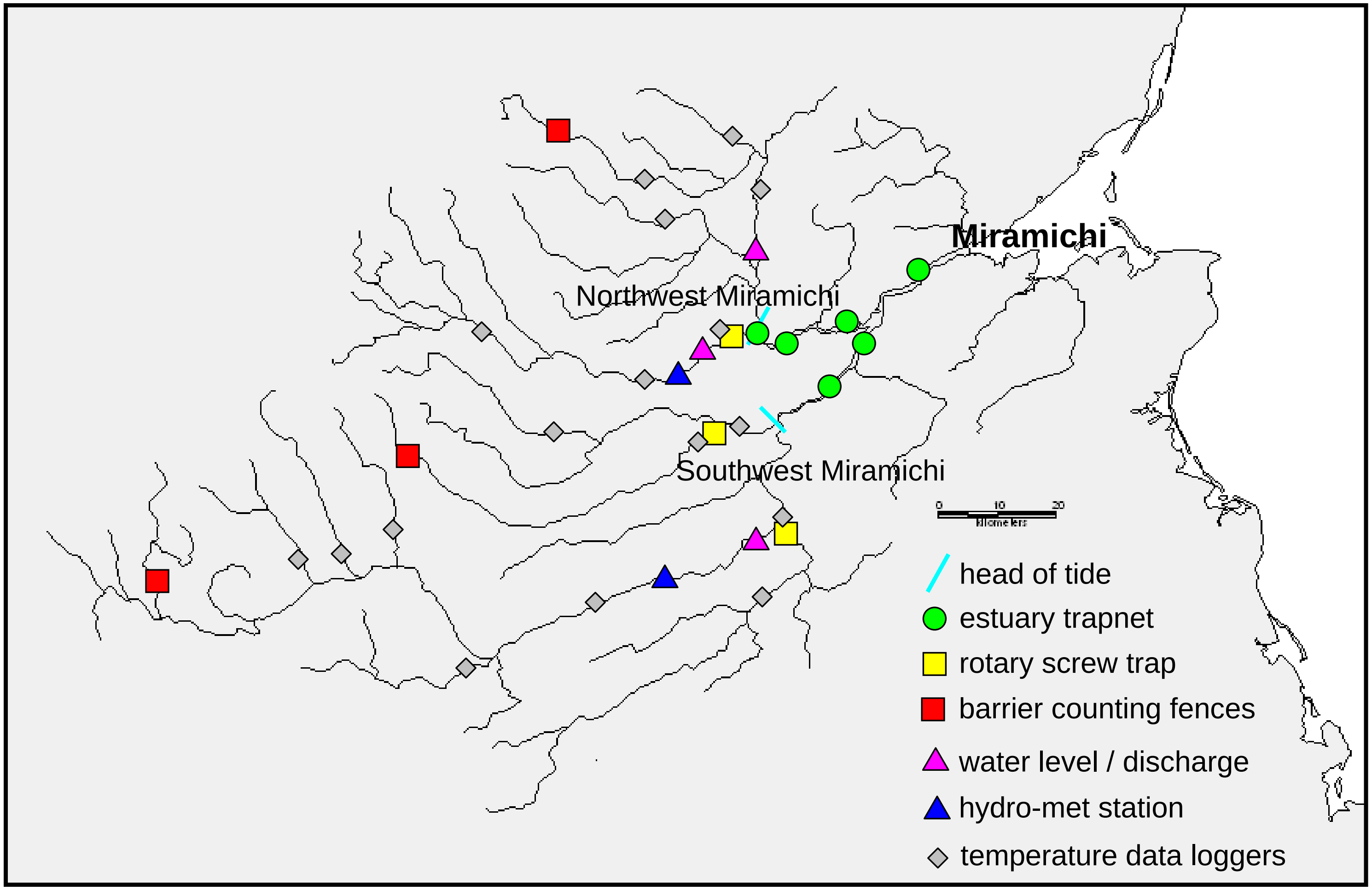


Figure 1. The Miramichi River watershed showing variety and placement of monitoring facilities.

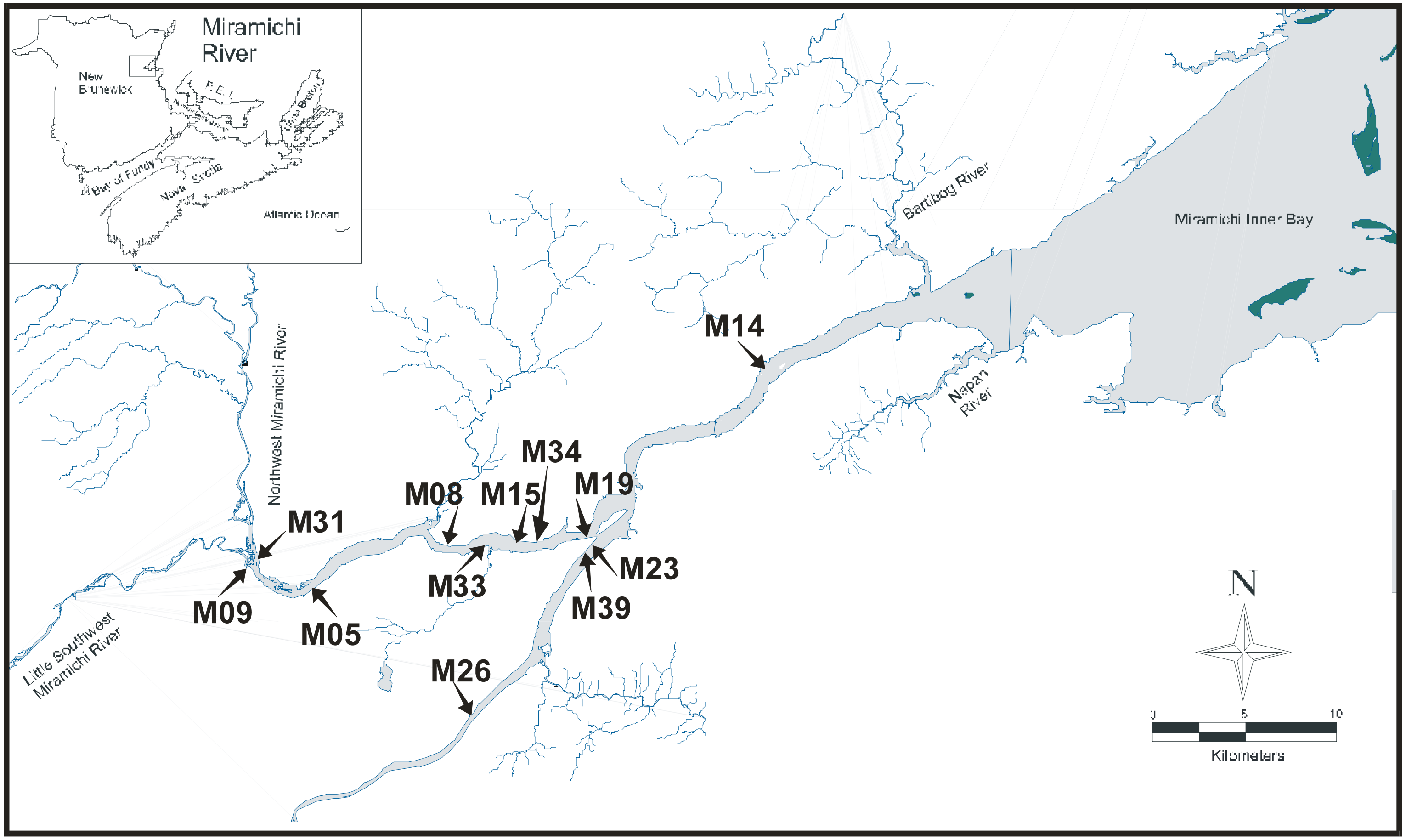


Figure 2. Location of tidal trapnets (facilities) in the Northwest and Southwest branches of the Miramichi River. Facility M14 is the Millbank trapnet in the main stem of the Miramichi which ceased operation in 1992.

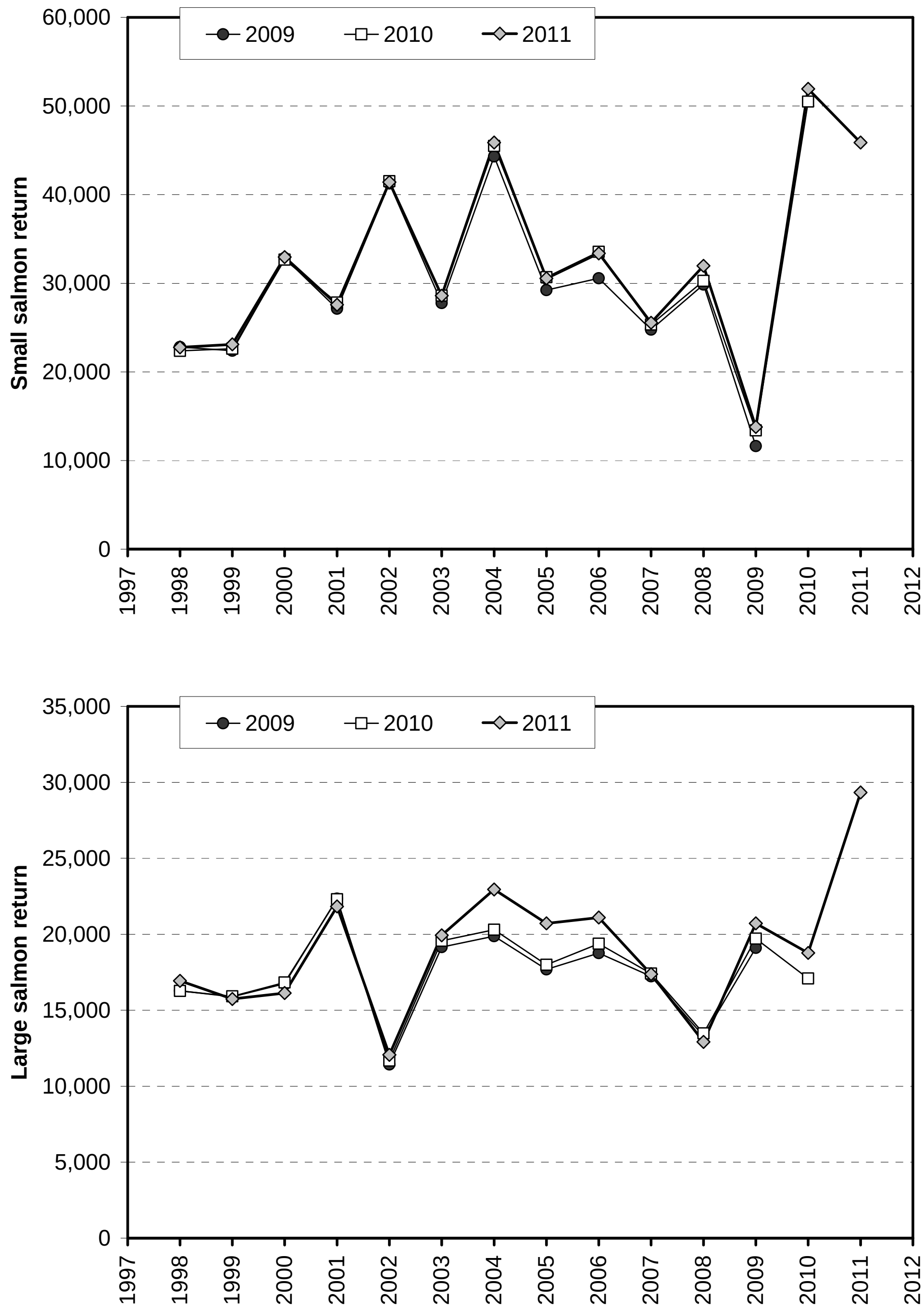


Figure 3a. Retrospective pattern of estimates of returns to the Miramichi River for three assessment years based on hierarchical model that treats counts at barriers as index of total run for the year (2009 model version – Chaput 2010).

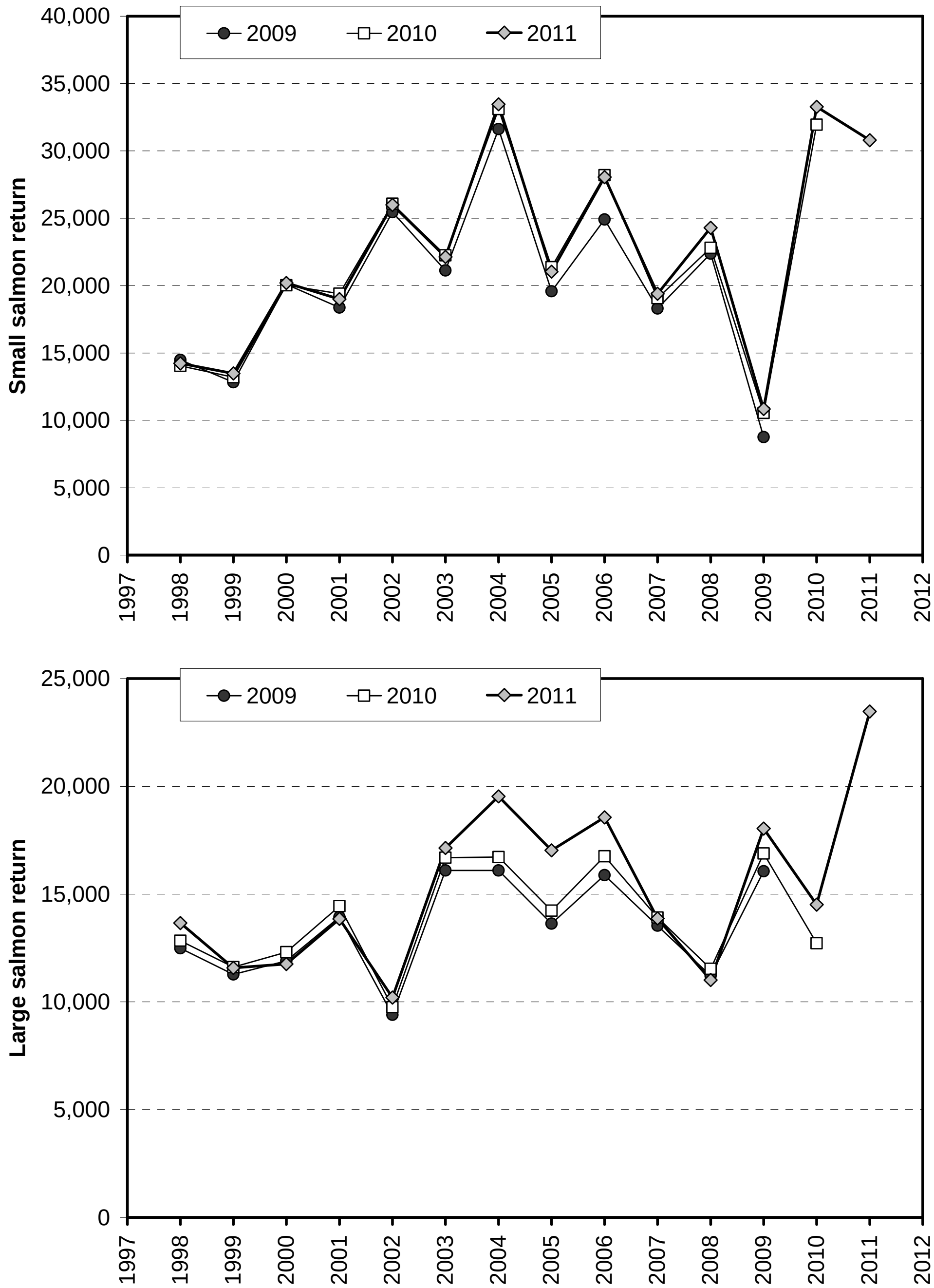


Figure 3b. Retrospective pattern of estimates of returns to the Southwest Miramichi River for three assessment years based on hierarchical model that treats counts at barriers as index of total run for the year (2009 model version – Chaput 2010).

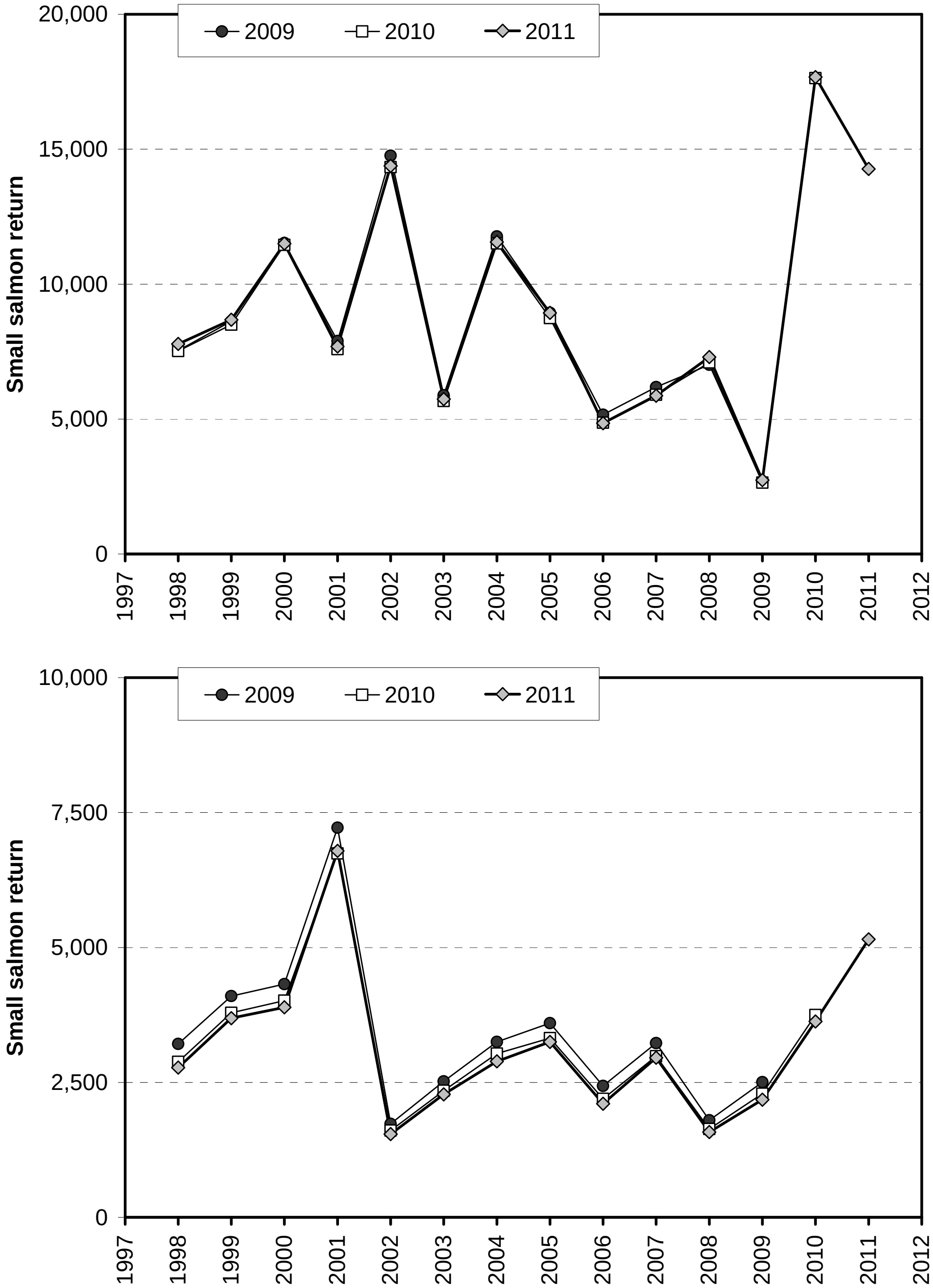


Figure 3c. Retrospective pattern of estimates of returns to the Northwest Miramichi River for three assessment years based on hierarchical model that treats counts at barriers as index of total run for the year (2009 model version – Chaput 2010).

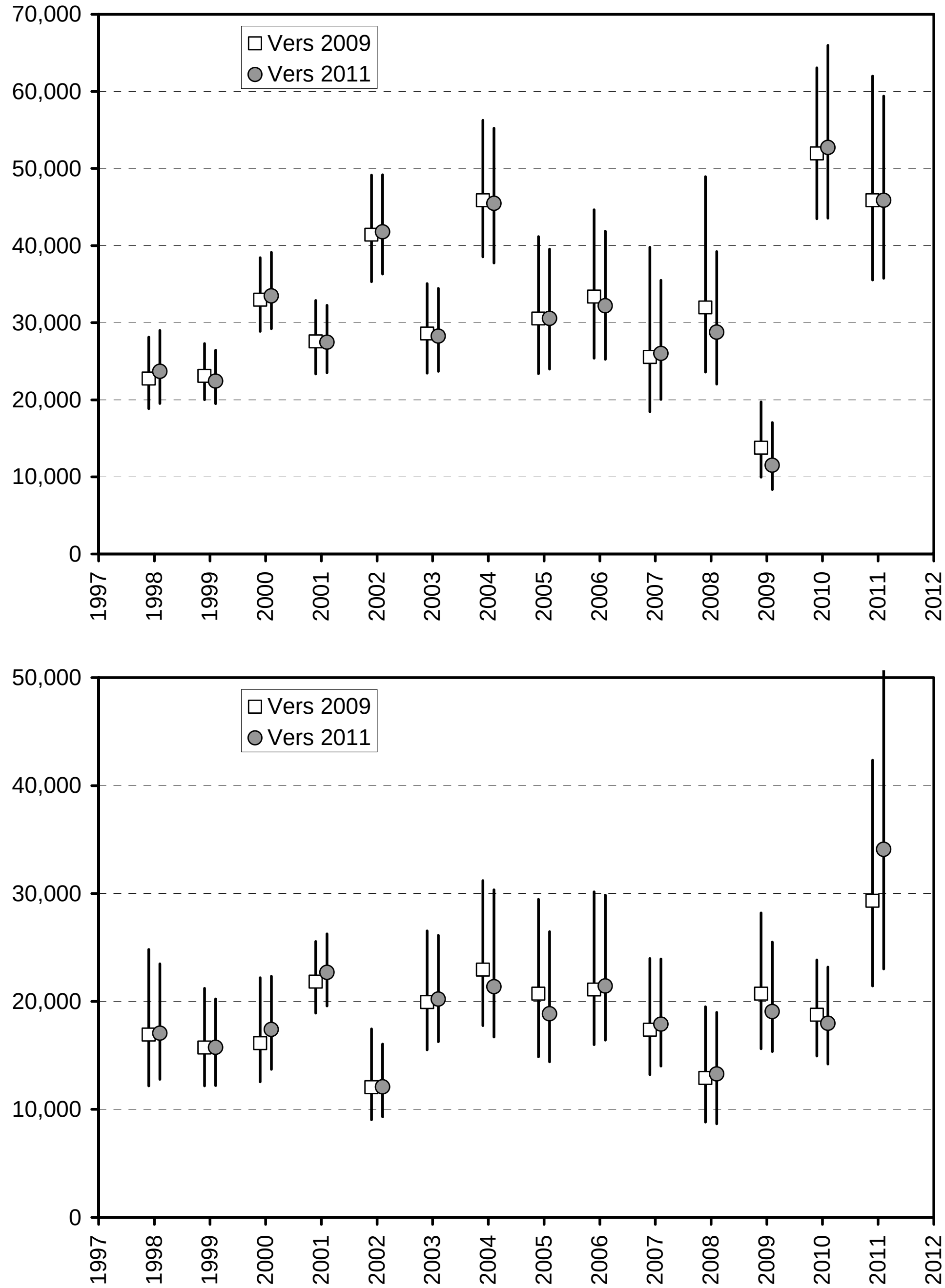


Figure 4a. Estimated returns based on model structure to the Miramichi River, 1998 to 2011 for small salmon (upper panel) and large salmon (lower panel).

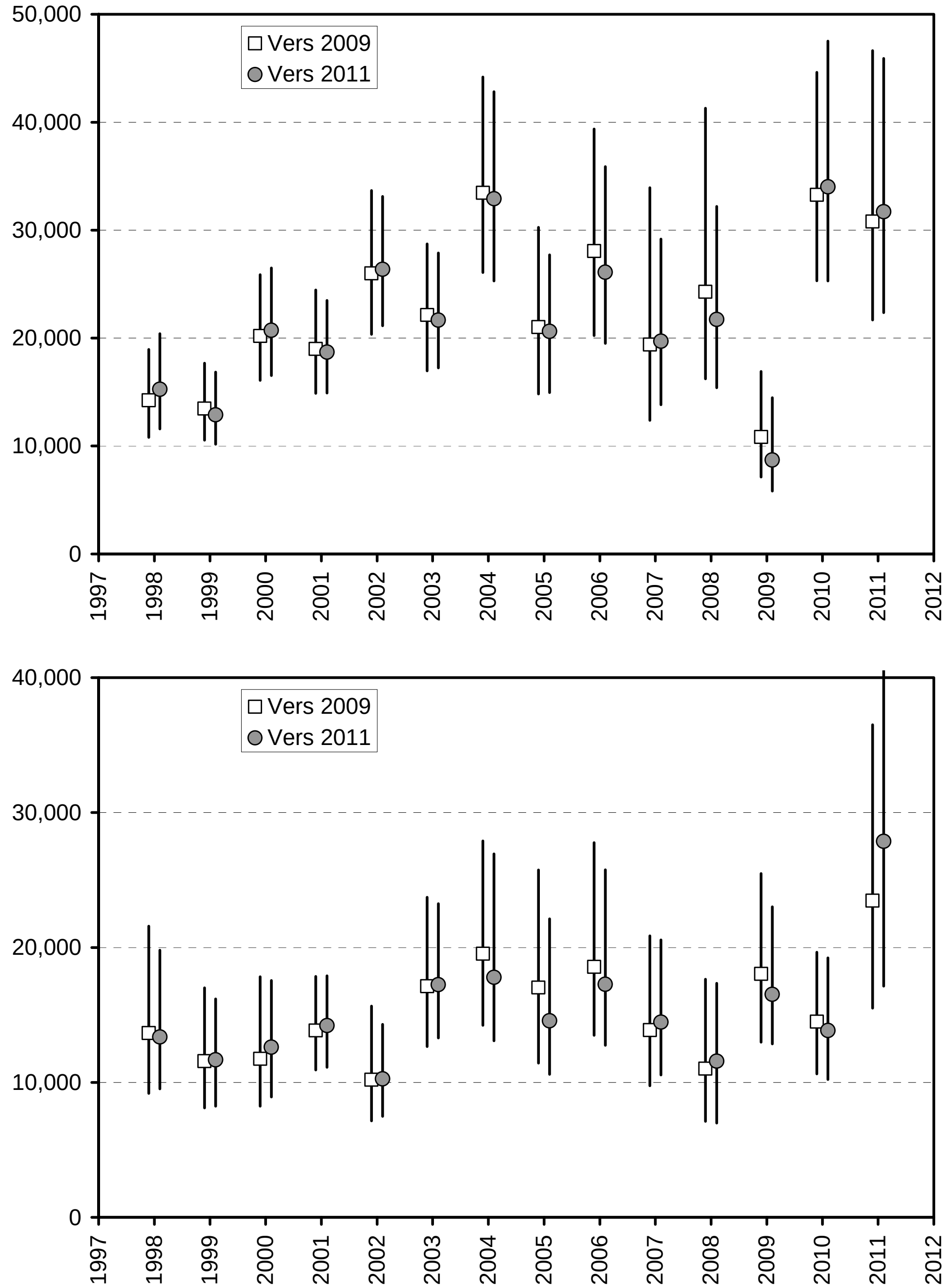


Figure 4b. Estimated returns based on model structure to the Southwest Miramichi River, 1998 to 2011 for small salmon (upper panel) and large salmon (lower panel).

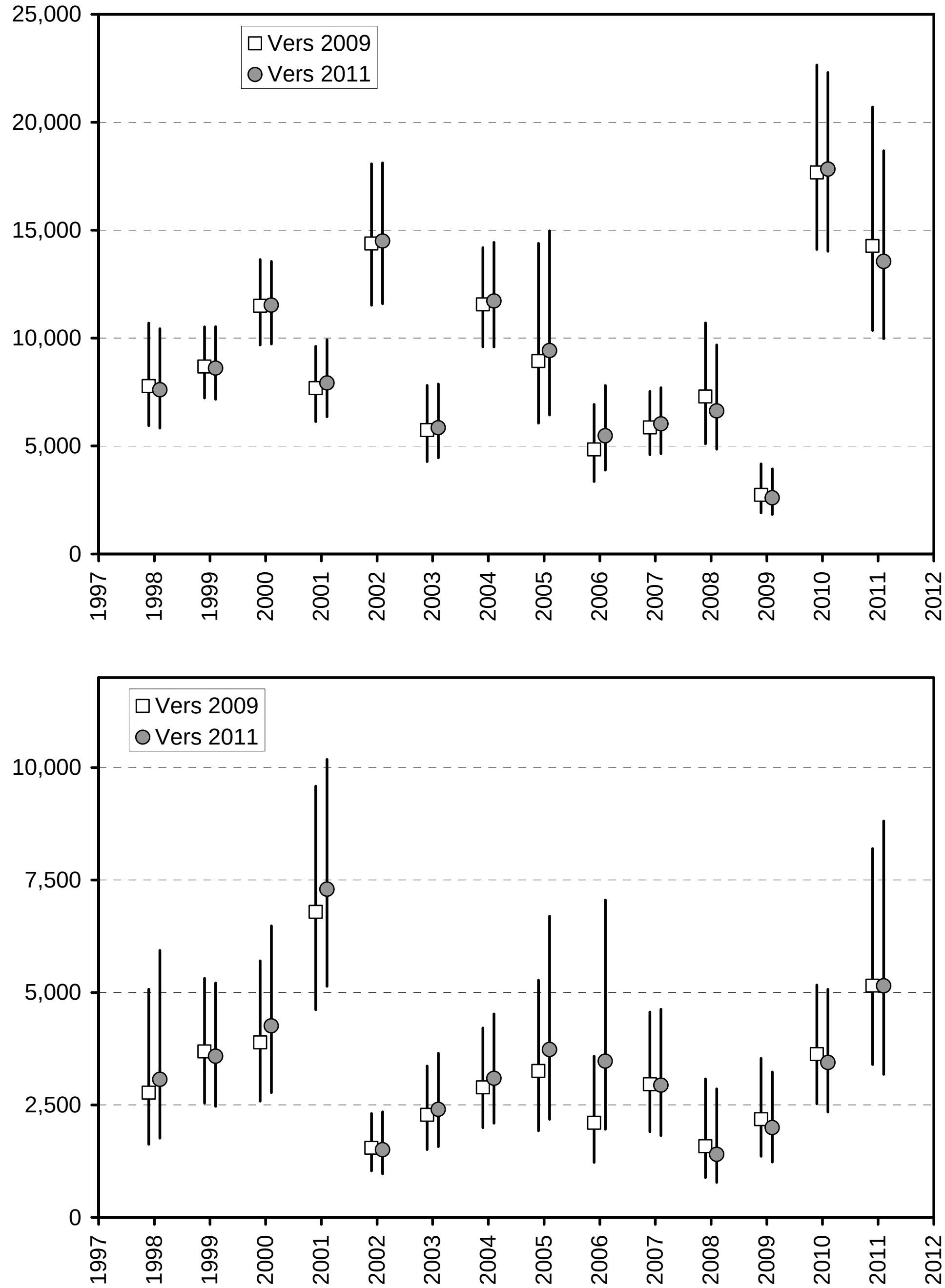
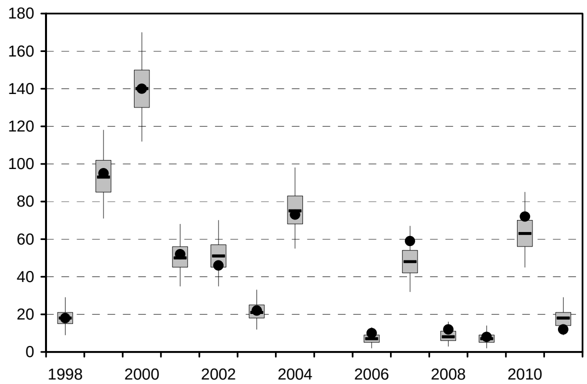
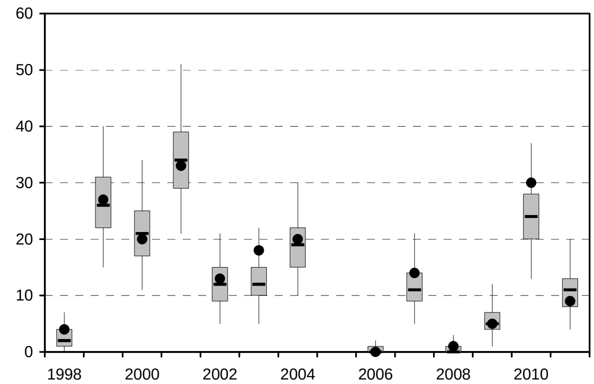


Figure 4c. Estimated returns based on model structure to the Northwest Miramichi River, 1998 to 2011 for small salmon (upper panel) and large salmon (lower panel).

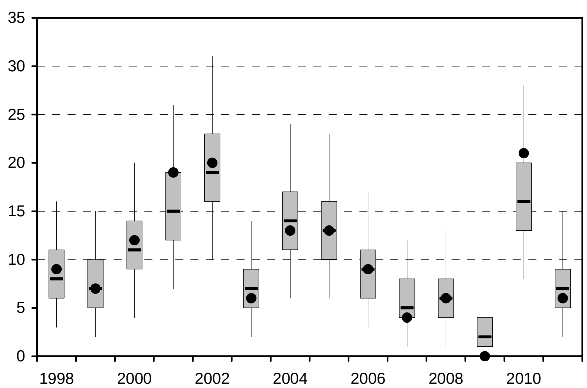
Small salmon **Large salmon**

NW RedBank





SW Millerton



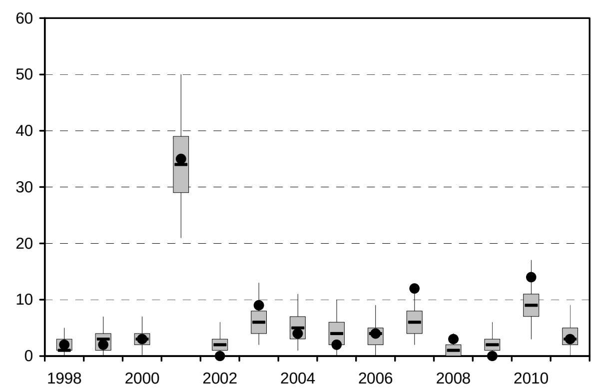
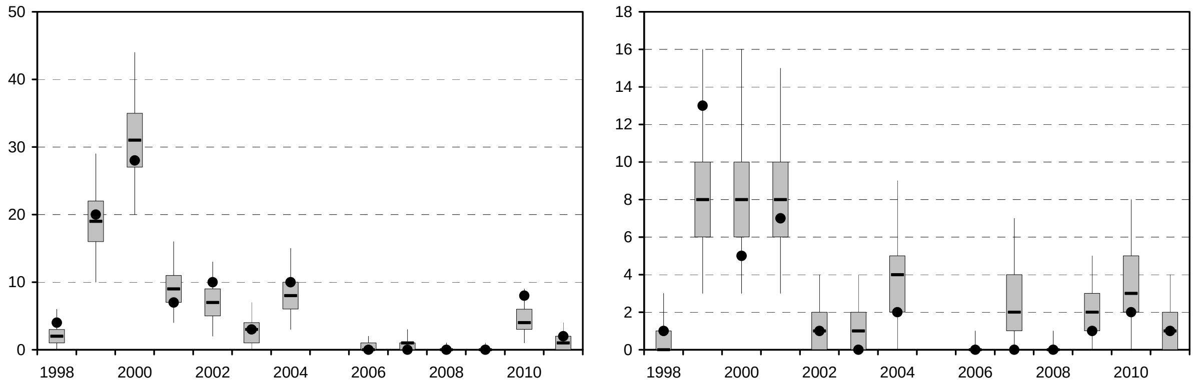


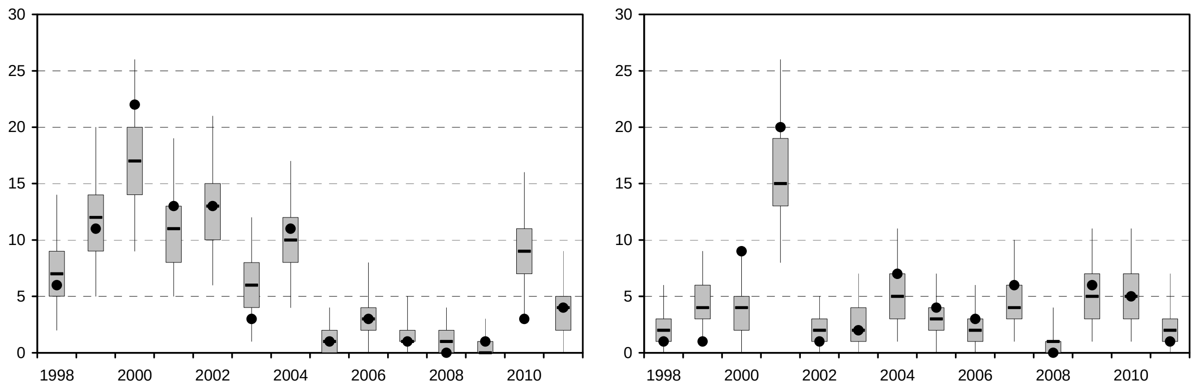
Figure 5. Predicted versus observed recaptures of small salmon (left panels) and large salmon (right panels) tagged at the NW Cassilis trapnet and recaptured in the NW Red Bank trapnets (upper panel) and the SW Millerton trapnet (lower panel), 1998 to 2011. Observed recaptures are the black circle. The boxplots are interpreted as follows: the vertical line is the 2.5th to 97.5th percentile range, the rectangle is the interquartile range and the dash is the median.

Small salmon **Large salmon**

NW RedBank



NW Cassilis



SW Millerton

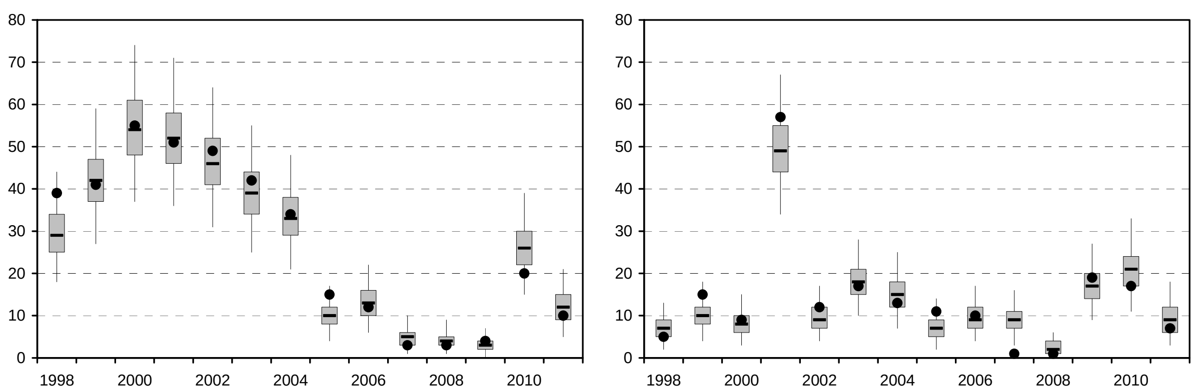
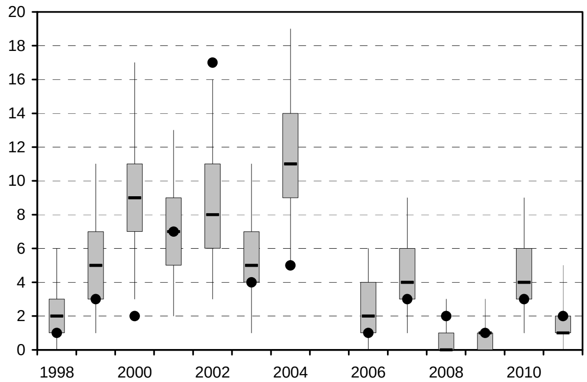
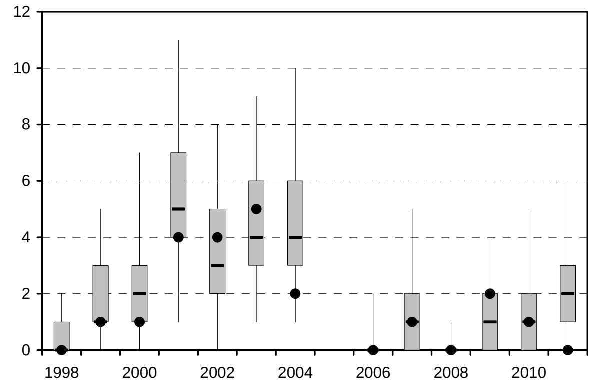


Figure 5 (continued). Predicted versus observed recaptures of small salmon (left panels) and large salmon (right panels) tagged at the SW Lower trapnet and recaptured in the NW Red Bank trapnets (upper panel), NW Cassilis trapnet (middle panel) and the SW Millerton trapnet (lower panel), 1998 to 2011. Observed recaptures are the black circle. The boxplots are interpreted as follows: the vertical line is the 2.5th to 97.5th percentile range, the rectangle is the interquartile range and the dash is the median.

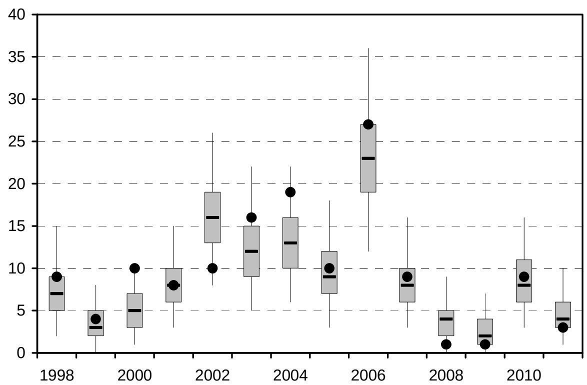
Small salmon **Large salmon**

NW RedBank





NW Cassilis



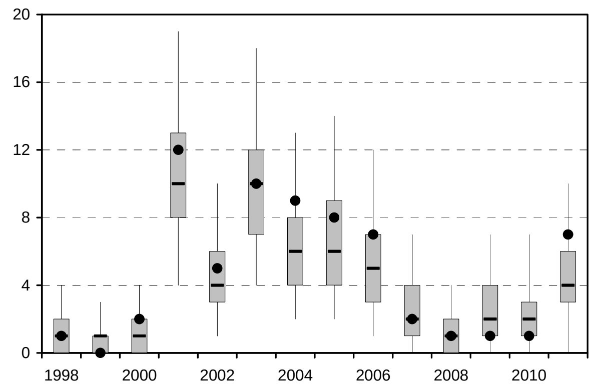


Figure 5 (continued). Predicted versus observed recaptures of small salmon (left panels) and large salmon (right panels) tagged at the SW Millerton trapnet and recaptured in the NW Red Bank trapnets (upper panel), and the NW Cassilis trapnet (lower panel), 1998 to 2011. Observed recaptures are the black circle. The boxplots are interpreted as follows: the vertical line is the 2.5th to 97.5th percentile range, the rectangle is the interquartile range and the dash is the median.

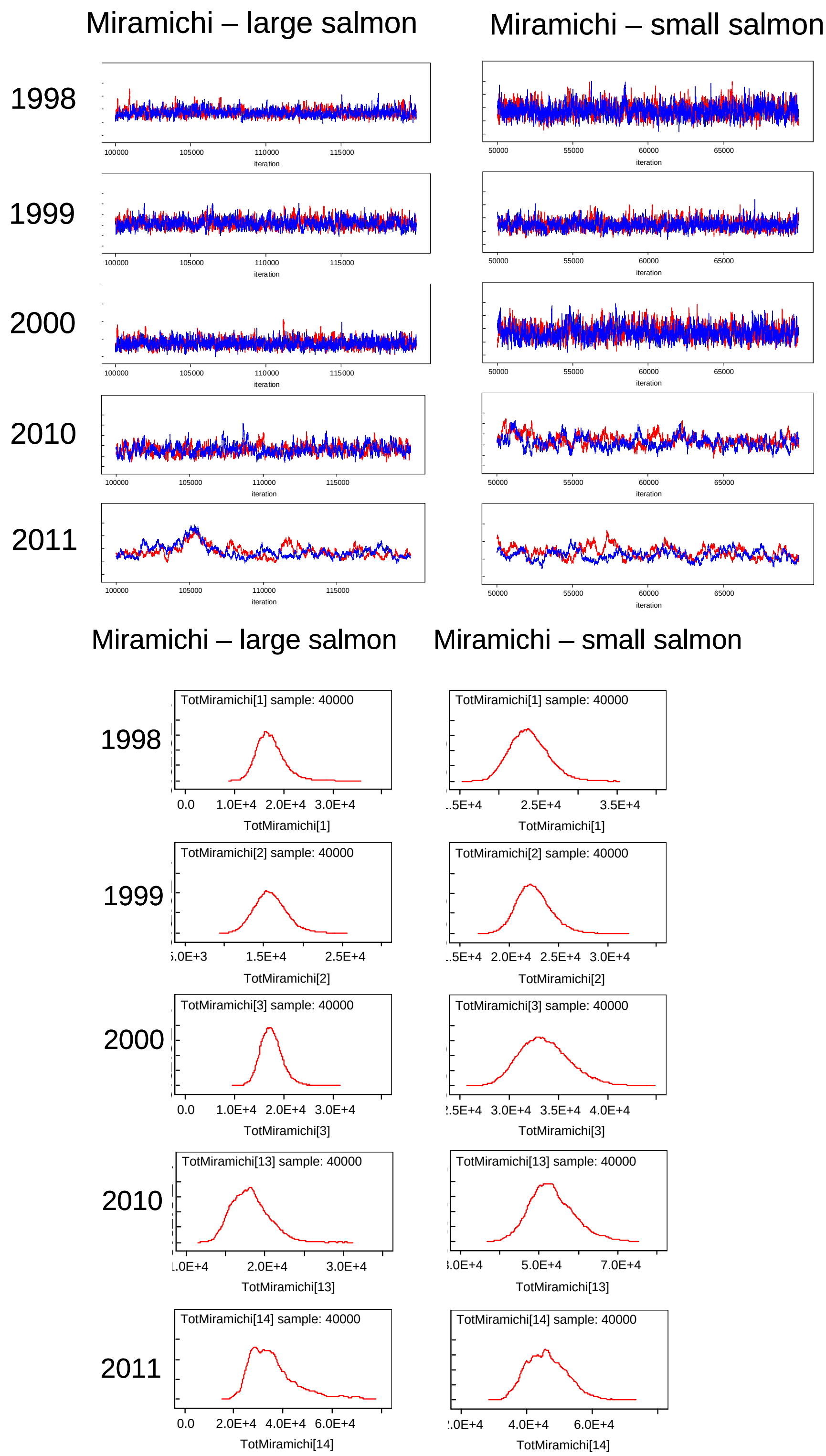


Figure 6. Diagnostics for assessing convergence of the Bayesian hierarchical model. Shown are the history of the MCMC draws from the posterior, smoothed posterior distribution, and Gelman-Rubick convergence plot for total returns to the Miramichi by size group, for example years 1998, 1999, 2000, 2010, and 2011.

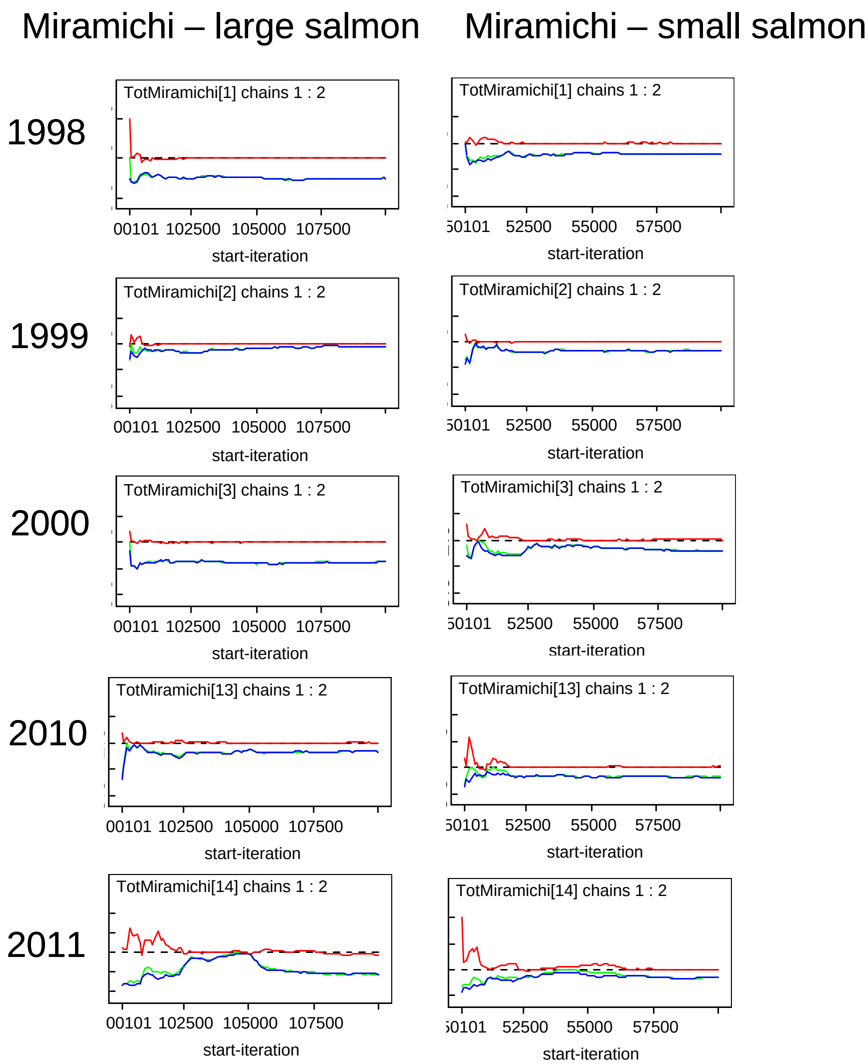
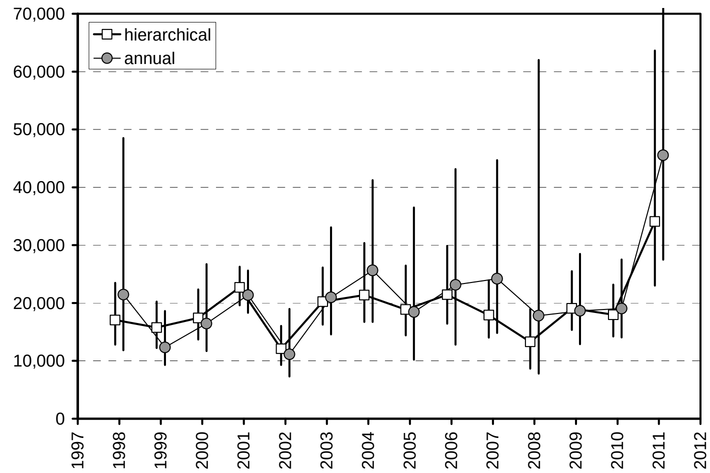


Figure 6 (continued). Diagnostics for assessing convergence of the Bayesian hierarchical model. Shown are the history of the MCMC draws from the posterior, smoothed posterior distribution, and Gelman-Rubick convergence plot for total returns to the Miramichi by size group, for example years 1998, 1999, 2000, 2010, and 2011.

Large salmon

	Coefficient of variation	
Year	Hierarchical	Annual
1998	16%	40%
1999	13%	19%
2000	12%	23%
2001	7%	9%
2002	14%	26%
2003	12%	22%
2004	16%	24%
2005	16%	34%
2006	16%	32%
2007	14%	31%
2008	20%	68%
2009	13%	21%
2010	13%	18%
2011	27%	34%



Small salmon

	Coefficient of variation	
Year	Hierarchical	Annual
1998	10%	12%
1999	8%	10%
2000	8%	8%
2001	8%	10%
2002	8%	9%
2003	10%	13%
2004	10%	13%
2005	13%	48%
2006	13%	28%
2007	15%	62%
2008	15%	52%
2009	19%	87%
2010	10%	17%
2011	13%	25%

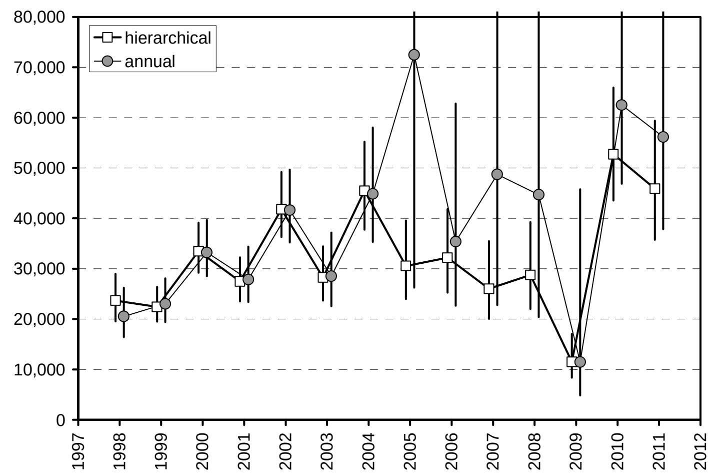
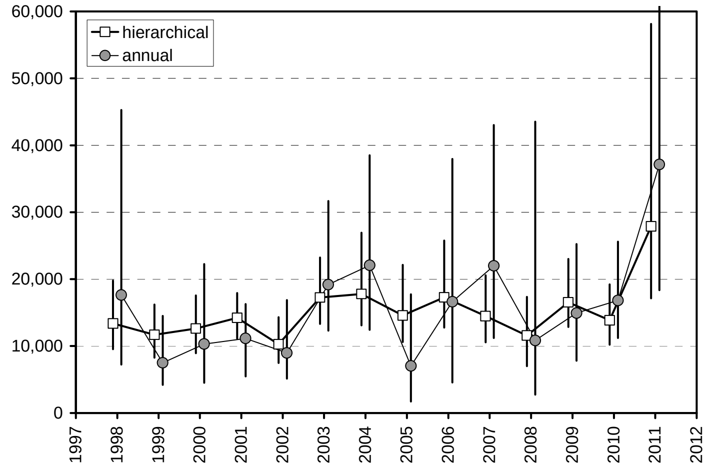


Figure 7a. Shrinkage of posterior inferences of abundance of small salmon (upper) and large salmon (lower) for the Miramichi River from annual models compared to the hierarchical models.

Large salmon

	Coefficient of variation	
Year	Hierarchical	Annual
1998	19%	49%
1999	17%	34%
2000	17%	42%
2001	12%	22%
2002	17%	32%
2003	14%	25%
2004	20%	30%
2005	20%	56%
2006	19%	49%
2007	17%	36%
2008	22%	80%
2009	15%	29%
2010	17%	21%
2011	33%	43%



Small salmon

	Coefficient of variation	
Year	Hierarchical	Annual
1998	15%	20%
1999	13%	17%
2000	12%	15%
2001	12%	16%
2002	12%	18%
2003	13%	17%
2004	14%	19%
2005	16%	54%
2006	16%	33%
2007	20%	68%
2008	20%	58%
2009	24%	111%
2010	16%	24%
2011	18%	46%

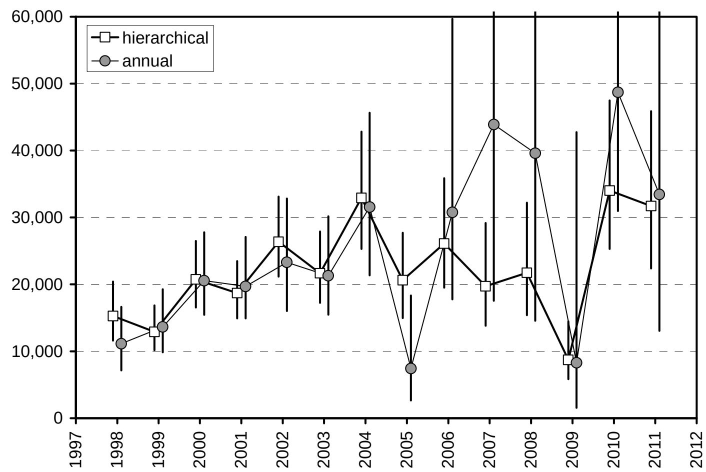
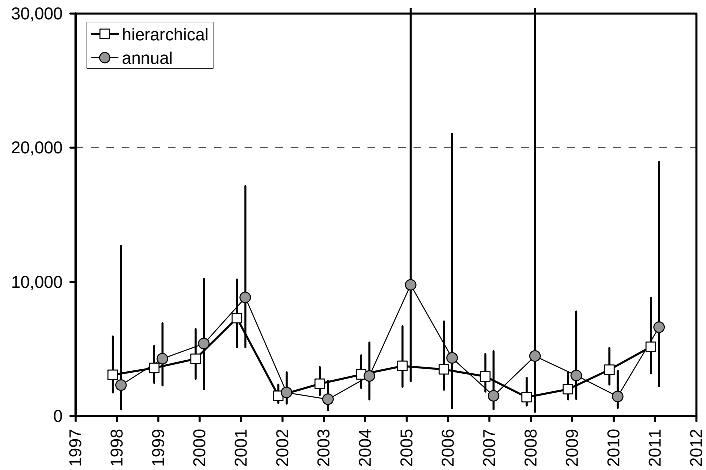


Figure 7b. Shrinkage of posterior inferences of abundance of small salmon (upper) and large salmon (lower) for the Southwest Miramichi River from annual models compared to the hierarchical models.

Large salmon

	Coefficient of variation	
Year	Hierarchical	Annual
1998	33%	103%
1999	19%	27%
2000	22%	38%
2001	17%	30%
2002	23%	33%
2003	22%	45%
2004	20%	34%
2005	30%	64%
2006	35%	91%
2007	24%	64%
2008	37%	144%
2009	25%	51%
2010	20%	46%
2011	27%	57%



Small salmon

	Coefficient of variation	
Year	Hierarchical	Annual
1998	15%	27%
1999	10%	13%
2000	9%	11%
2001	11%	18%
2002	11%	17%
2003	15%	23%
2004	10%	14%
2005	22%	56%
2006	18%	45%
2007	13%	23%
2008	18%	39%
2009	20%	40%
2010	12%	21%
2011	16%	29%

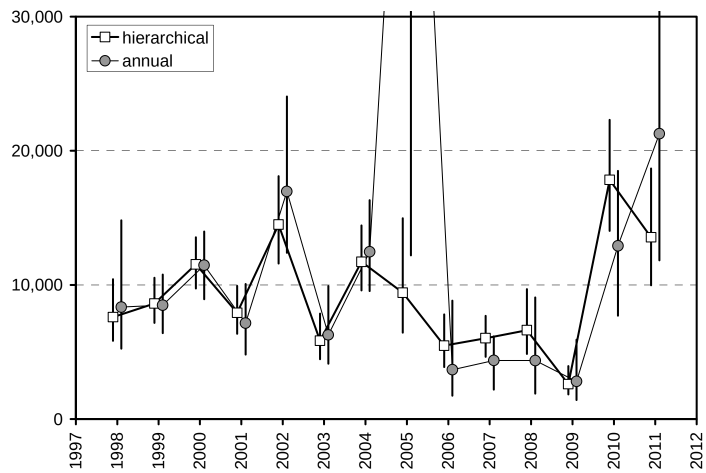
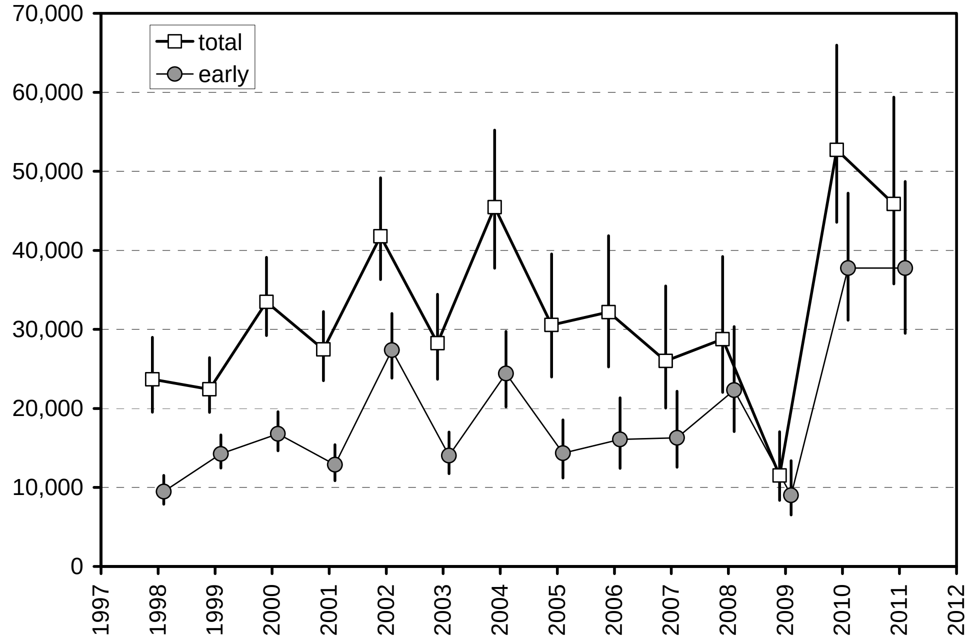


Figure 7c. Shrinkage of posterior inferences of abundance of small salmon (upper) and large salmon (lower) for the Northwest Miramichi River from annual models compared to the hierarchical models.



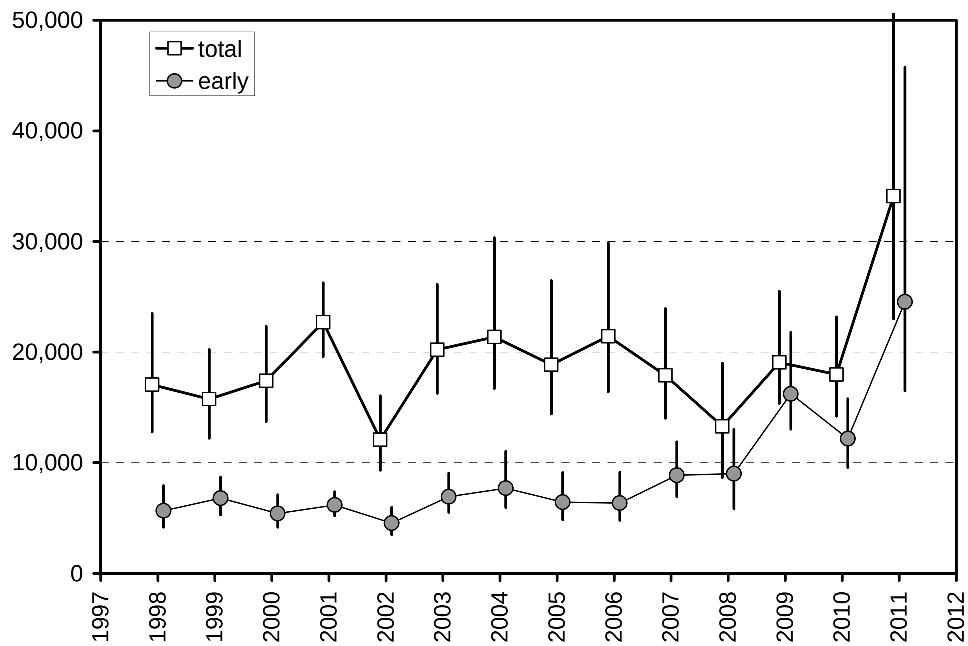


Figure 8a. Returns total and for the early run of small salmon (upper panel) and large salmon (lower panel) for the Miramichi River, 1998 to 2011. Based on the version 2011 model.

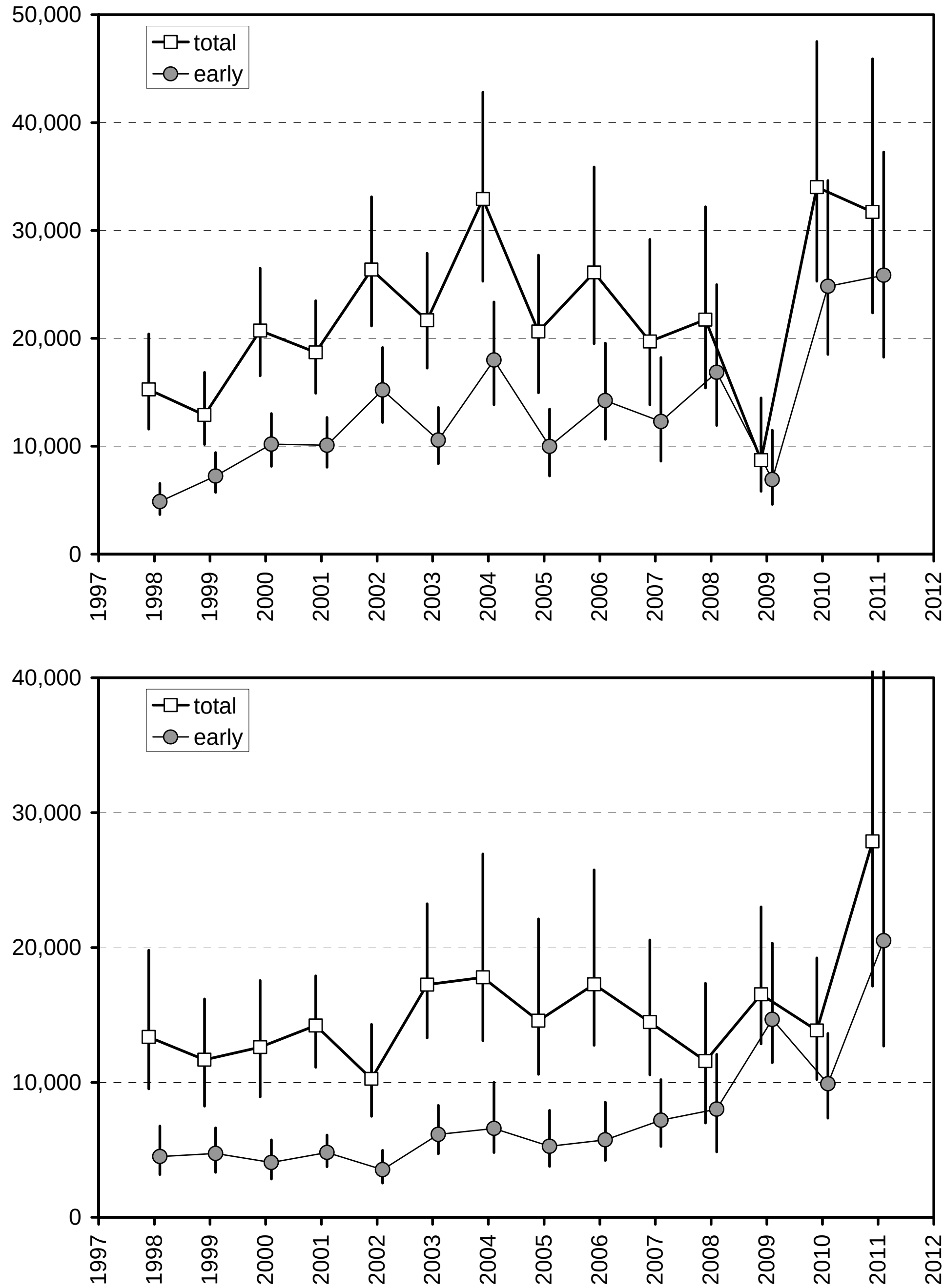


Figure 8b. Returns total and for the early run of small salmon (upper panel) and large salmon (lower panel) for the Southwest Miramichi River, 1998 to 2011. Based on the version 2011 model.

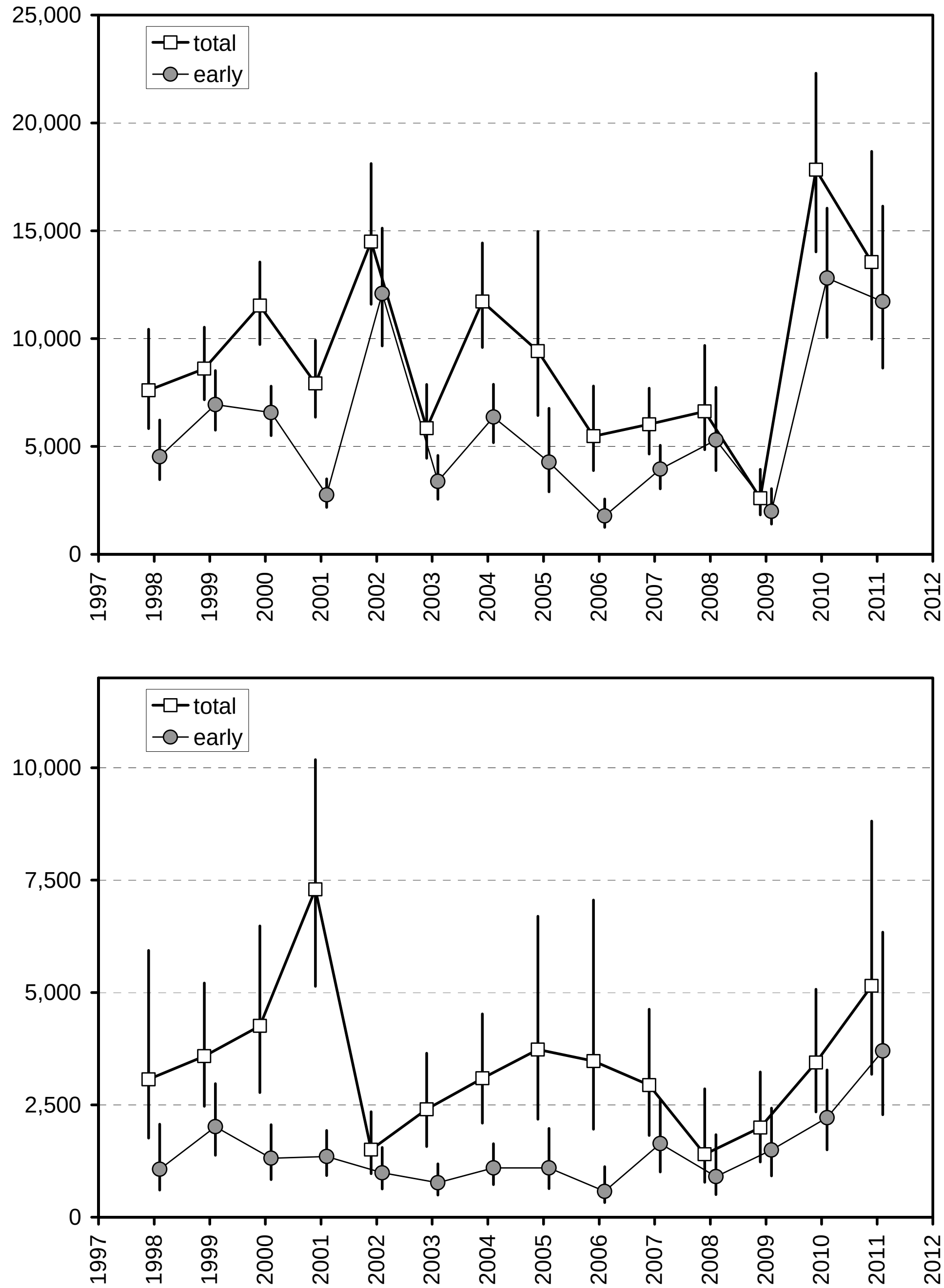


Figure 8c. Returns total and for the early run of small salmon (upper panel) and large salmon (lower panel) for the Northwest Miramichi River, 1998 to 2011. Based on the version 2011 model.

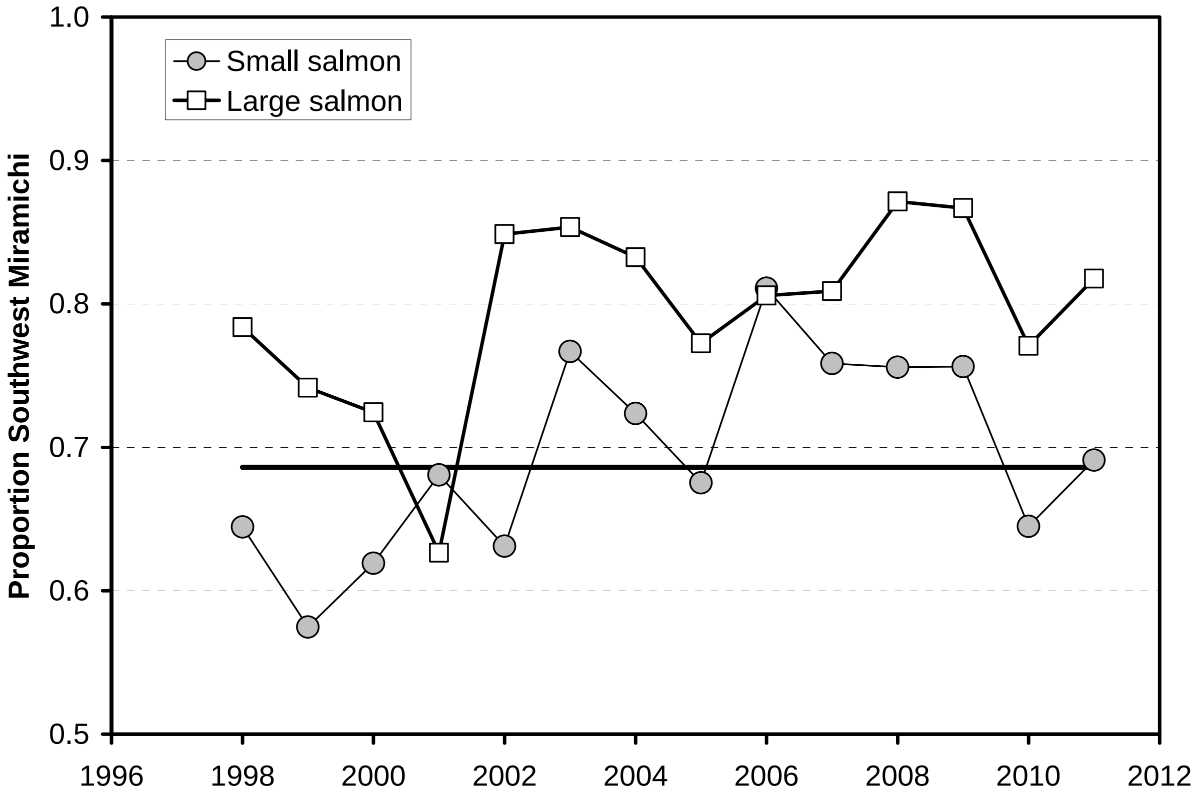


Figure 9. Estimated (based on median value) proportion that Southwest Miramichi returns are of the total returns to the Miramichi River, by small salmon and large salmon, 1998 to 2011. The solid horizontal line, at 0.686, is the proportion Southwest of the conservation egg requirements for the Northwest and Southwest branches.

Appendix 1. Mark and recapture models applied to the Miramichi adult salmon data.

The models are developed in a Bayesian framework in which prior information of the quantities of interest are updated using observations and likelihoods for those observations (Fig. A1-1). Acronyms, observations, likelihoods and priors are described in Tables A1-1 to A1-4.

The quantities of interest for the assessment are the annual returns of salmon by size group to the Northwest and Southwest branches (TotSW; TotNW) and to the Miramichi River overall. This cannot be measured directly as there is no complete enumerating system on this river. Expert opinion provides a range for the possible run size to this river, based on wetted area for juvenile production and an assumed population dynamic for salmon. The conservation spawning requirement for the Miramichi River and its two branches is based on a measure of wetted area for juvenile production and an egg deposition rate of 240 eggs per 100 m^2 (Chaput et al. 2001). Based on average biological characteristics, the conservation requirements are about 16,000 large salmon for the Southwest Miramichi and 7,300 fish for the Northwest Miramichi. Recruits per spawner of 5:1 would be very high production for Atlantic salmon and a return of 100, 000 large salmon would be an upper limit for the Miramichi. Catches of small salmon at trapnets are generally higher than for large salmon and returns of 200 to 300 thousand small salmon would be an upper limit to the maximum returns expected in each branch. The Southwest Miramichi has twice the juvenile production area of the Northwest Miramichi and returns to the former are expected to be about twice those of the latter.

			Fish required	
	Habitat area (million m^2)	Egg requirement (millions)	Large salmon	Small salmon
Miramichi River	54.6	132	23,600	22,600
Main Miramichi	1.1	3	554	531
Southwest Miramichi	36.7	88.1	15,730	15,063
Northwest Miramichi	16.8	40.3	7,316	7,006

Uninformative uniform prior distributions were chosen for the returns of small salmon and large salmon to each branch.

Branch	Size group	Distribution	Lower	Upper
Southwest	Small	Uniform	1,000	500,000
	Large	Uniform	1,000	200,000
Northwest	Small	Uniform	100	300,000
	Large	Uniform	100	100,000

To update the prior information on returns, we can use several indicators of salmon abundance in Miramichi including catches at estuary trapnets and counts at headwater protection barriers. All of these are partial measurements of the total returns. The objective is to estimate the raising factors of these indicators to the total returns of salmon.

The indicators of abundance for the Miramichi were modelled as having come from a binomial process with the successes (samples or catches) dependent on the number of trials (total run of fish to the river) and the probability of success (the proportion of the total run which is sampled or caught) (Table A1-2; A1-4).

The hierarchical model structure allows the transfer of information over all years . In the following simple example:

$[catch_i \mid p_i, N_i] \sim \text{binomial}(p_i, N_i)$

the probability of having observed $catch_i$ given the probability of capture in year i and the run size in year i is binomial with parameters p_i, N_i

$p_i \sim beta(a, b)$

p_i is beta distributed with parameters a and b

p_i is the “true” probability of capture (trapnet efficiency) in year i and the p_i’s are a random sample (over years) from a common population distribution. The trapnet efficiencies are assumed to be similar but not identical. The beta(a,b) prior describes the distribution of fishing efficiency among the years. A joint probability model for the entire set of parameters (p_i,a,b) is developed and prior distributions are assigned to a and b.

Rather than setting priors directly on a and b, priors were set on the mean and variance of the Beta(a, b) distribution (Rivot and Prevost 2002). After alternate variable transformation, an uninformative prior distribution which is essentially uniform over the interval 0 to 1 for the p_i’s is obtained from:

$E \sim beta(1.5,1.5)$

$u \sim beta(1, 10)$

$a_i = E\,(1 – u) / u$

$b_i = (1 – E) * (1 – u) / u$

$p_i \sim beta(a_i, b_i)$

In annual models, neither the barrier count data nor the recreational fishing data are informative because the proportion of the run which goes to the barriers or is angled is estimated from the run size which is derived from the mark and recapture data. In the hierarchical model, the barrier data are used and an overall proportion of the run which goes to the barriers can be estimated over all the years with mark and recapture data. The overall proportion can then be applied to the years when no mark and recapture data are available. This is the same case for the recreational fisheries data.

The models were run using Monte Carlo Markov Chain with the Gibbs sampler in “OpenBugs” (Spiegelhalter et al. 2010).

Appendix Table A1-1. Acronym definitions for the observations in the hierarchical Miramichi salmon model, 1998 to 2011. Subscripts for year and size group are dropped for convenience.

Observations

Counts at headwater protection barriers

NNWMir Count of fish at the NW Miramichi barrier

NJunip Count of fish at the SW Miramichi Juniper barrier

NDung Count of fish at the SW Miramichi Dungarvon barrier

Catches in estuary trapnets

FTSMid Catches (first time) at SW Miramichi Millerton trapnet

FTNMid Catches (first time) at the NW Miramichi Cassilis trapnet

FTNHigh Catches (first time) at the NW Miramichi Redbank trapnets

Marked fish at trapnets

MSLow Fish tagged at SW Eelground trapnets

MSMid Fish tagged at SW Millerton trapnet

MNMid Fish tagged at NW Cassilis trapnet

Recaptures of previously tagged fish in estuary trapnets

RSMid	RSLowSMid	Recaptures of fish tagged at SW Eelground traps to SW Millerton trap
	RNMidSMid	Recaptures of fish tagged at NW Cassilis trap to SW Millerton trap
RNMid	RSLowNMid	Recaptures of fish tagged at SW Eelground traps to NW Cassilis trap
	RSMidNMid	Recaptures of fish tagged at SW Millerton trap to NW Cassilis trap
RNHigh	RSLowNHigh	Recaptures of fish tagged at SW Eelground traps to NW RedBank trap
	RSMidNHigh	Recaptures of fish tagged at SW Millerton trap to NW RedBank trapnets
	RNMidNHigh	Recaptures of fish tagged at NW Cassilis trap to NW RedBank trapnets

Appendix Table A1-2. Acronym definitions for the likelihoods of observations in the hierarchical Miramichi salmon model, 1998 to 2011. Subscripts for year and size group are dropped for convenience.

<u>Likelihoods for observations</u>

NJunip ~ bin(pJunip, TotS)

NDung ~ bin(pDung, TotSE)

NNWMir ~ bin(pNWMir, TotNE)

FTSMid ~ bin(EFSMid, TotS)

FTNMid ~ bin(EFNMid, TotN)

FTNHigh ~ bin(EFNHigh, TotN)

RSMid ~ bin(EFSMid, (MSLowS+MNMidS))

RNMid ~ bin(EFNMid, (MSLowN+MSMidN))

RNHigh ~ bin(EFNHigh, (MSLowN+MSMidN+MNMidN))

Appendix Table A1-3. Acronym definitions of parameters of interest and their corresponding priors. Subscripts for year and size group are dropped for convenience.

TotSW	Returns to the SW Miramichi Prior: uniform(min, max)
TotNW	Returns to the NW Miramichi Prior: uniform(min, max)
pJunip	Proportion Juniper counts of returns to SW Miramichi prior: beta(a, b)
pDung	Proportion Dungarvon counts of early returns to SW Miramichi prior: beta(a, b)
pNWMir	Proportion NW Miramichi barrier counts of erly returns to NW Miramichi prior: beta(a,)
ESLowS	Probability of fish tagged in SW Eelground traps staying in SW Miramichi Prior: beta(a, b)
ESMidS	Probability of fish tagged in SW Millerton trap staying in SW Miramichi Prior: beta(a, b)
ENMidN	Probability of fish tagged in NW Cassilis trapnet staying in NW Miramichi Prior: beta(a, b)
EFSMid	Efficiency of SW Millerton trapnet Prior: beta(a, b)
EFNMid	Efficiency of NW Cassilis trapnet Prior: beta(a, b)
EFNHigh	Efficiency of NW RedBank trapnets Prior: beta(a, b)
pNWE	Proportion of returns in the early (before Aug. 1) portion of the season to the Northwest Miramichi Prior(NWCassE, NWCassL)
pSWE	Proportion of returns in the early (before Aug. 1) portion of the season to the Southwest Miramichi Prior(SWMillE, SWMillL)

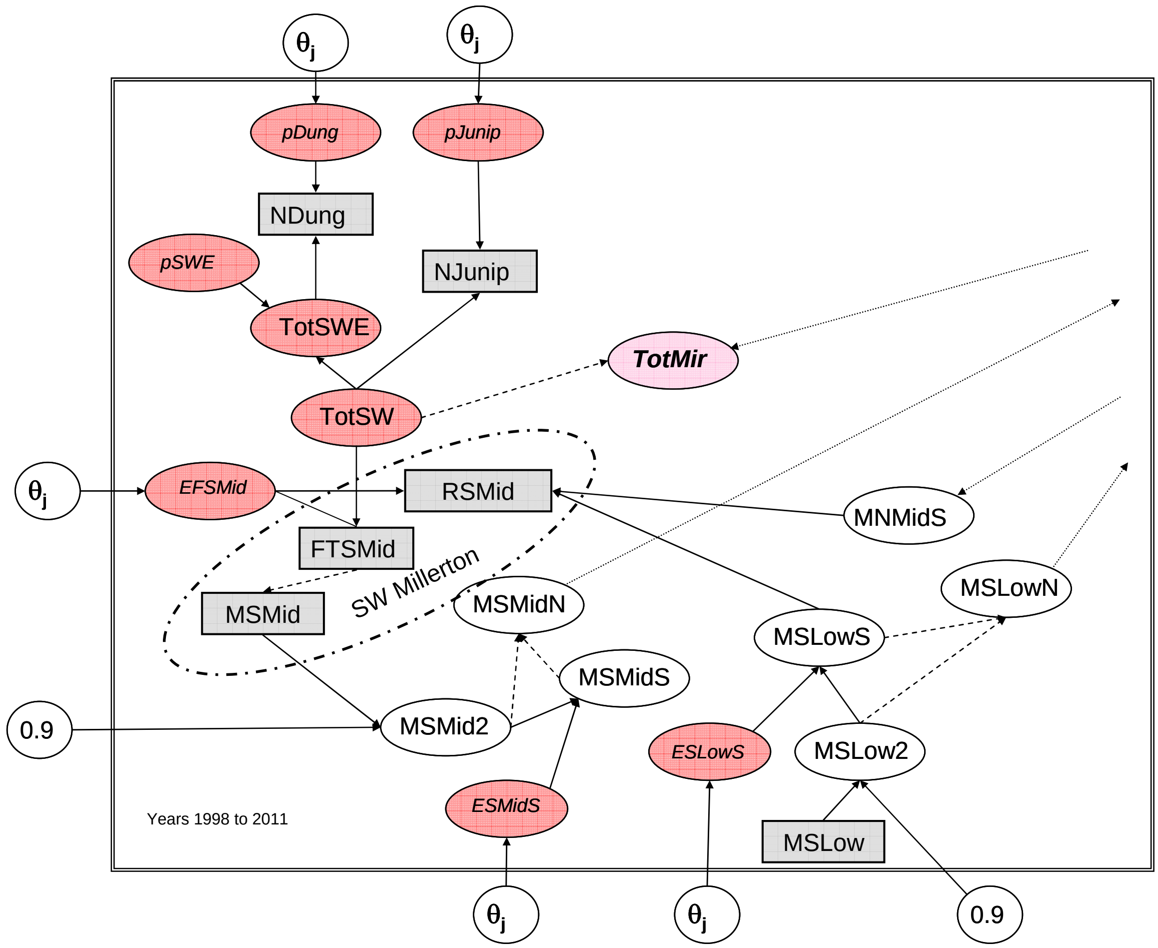
<u>For hierarchical model:</u>

a = E (1 – u) / u
b = (1 – E) * (1 – u) / u
E ~ beta(1.5,1.5)
U ~ beta(1, 10)

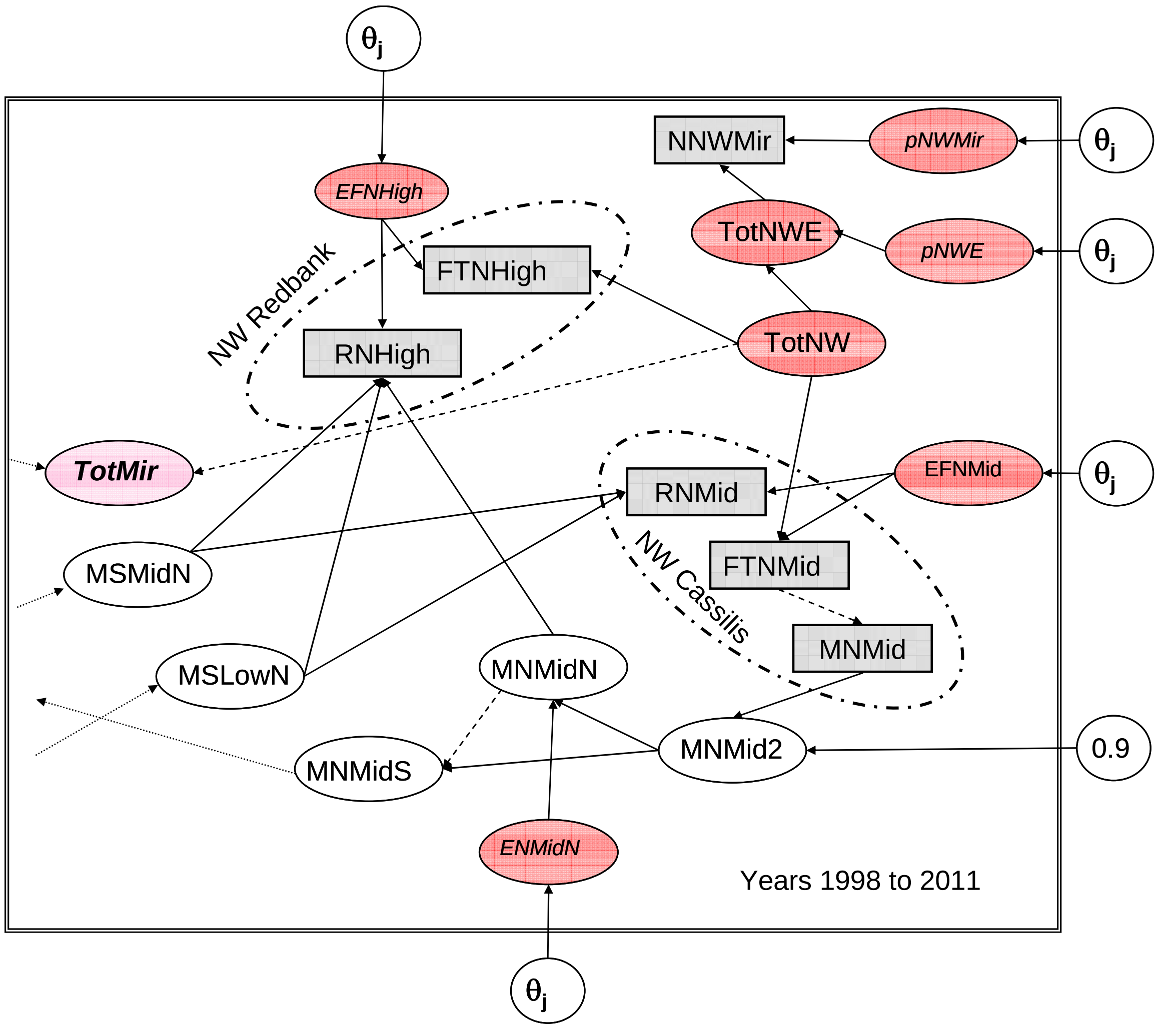
Appendix Table A1-4. Acronym definitions of latent variables and their likelihoods. Subscripts for year and size group are dropped for convenience.

Latent variables

MSLow2	Tags available from SW Eelground after correcting for tagging and handling mortality ~ bin(0.9, MSLow)
MSMid2	Tags available from SW Millerton after correcting for tagging and handling mortality ~ bin(0.9, MSMid)
MNMid2	Tags available from NW Cassilis after correcting for tagging and handling mortality ~ bin(0.9, MNMid)
MSLowS	Tagged fish from SW Eelground traps available for recapture at traps in SW ~ bin(ESLowS, MSLow)
MSLowN	Tagged fish from SW Eelground traps available for recapture at traps in NW = MSLow – MSLowS
MSMidS	Tagged fish from SW Millerton trap available for recapture at trasp in SW ~ bin(ESMidS, MSMid)
MSMidN	Tagged fish from SW Millerton trap available for recapture at traps in NW = MSMid - MSMidS
MNMidN	Tagged fish from NW Cassilis trap available for recapture at traps in NW ~ bin(ENLowN, MNLow)
MNMidS	Tagged fish from NW Cassilis trap available for recapture in SW traps = MNMid - MNMidN
TotMir	Returns to the Miramichi River = TotS + TotN
TotMirE	Returns in the early part of the season to the Miramichi River = TotSE + TotNE



Appendix Figure A1-1. Partial DAG of the hierarchical model (1998 to 2011) for the Southwest Miramichi trapnet and barrier fence catches. Items in grey are the observations, items in red are the variables of interest to be estimated by the model. Items in white ellipses are latent variables. Items outside the frame are the hyperparameter (and their distributions) estimated by the model. Acronyms are as in Appendix Tables A4-1-A4-4.



Appendix Figure A1-2. Partial DAG of the hierarchical model (1998 to 2011) for the Northwest Miramichi trapnet and barrier fence catches. Items in grey are the observations, items in red are the variables of interest to be estimated by the model. Items in white ellipses are latent variables. Items outside the frame are the hyperparameter (and their distributions) estimated by the model. Acronyms are as in Appendix Tables A4-1-A4-4.