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Reproductive rates and rebuilding potential for two multi-sea-winter Atlantic salmon (*Salmo salar* L.) stocks of the Maritime provinces

Taux de reproductions et potentiel d'agrandissement de deux populations pluribermarin de Saumon atlantique (*Salmo salar* L.) des provinces Maritimes

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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 two multi-sea-winter Atlantic salmon (*Salmo salar* L.) stocks of the Maritime provinces of eastern Canada are compared and life history based characteristics and population dynamics are related to variations in abundance. Possible factors and life history stages which may be constraining the viability and the rebuilding potential of the stocks are discussed. The prognosis for the Miramichi River population remains positive as marine return rates appear sufficient for the population to replace itself. Size at age has increased and every female has the potential to produce more eggs than in the past, and there is a high survival to second and third spawning. Juvenile production remains high. The outstanding question is whether intra and inter-cohort competition of the juveniles is resulting in density dependent mortality of parr in the winter prior to smolting or whether reduced adult abundance is the result of reduced marine survival. Both factors are plausible for the Miramichi stock. The Saint John River population has generally failed to replace itself throughout the time period 1972 to 2004. For the last ten year classes, the lifetime egg production has been substantially below replacement. The dramatic decline in wild salmon reproductive rate strongly suggests that the increased mortality on the wild salmon post 1989 may in part be driven by a freshwater constraint associated with the environment at and above Mactaquac. Rebuilding potential for this stock in the absence of intervention is poor.

Résumé

L'état de deux populations pluribermarins de Saumon atlantique (*Salmo salar* L.) des provinces maritimes de l'est du Canada est comparé. Les caractéristiques du cycle vital et des indices de dynamiques de populations sont présentés par rapport aux variations d'abondance. Des facteurs et les stades de vie qui pourraient contraindre la viabilité et le potentiel d'agrandissement de ces populations sont discutés. Le pronostic de la population de la rivière Miramichi est positif. Les taux de retour de la mer sont suffisants pour maintenir la population. Les taux de survie à un deuxième et troisième frai ont aussi augmenté. La taille à l'âge a augmenté et en conséquence les femelles produisent plus d'œufs par individu. Le niveau de production de juvéniles est élevé. Il demeure à savoir si la baisse d'abondance des saumons adultes est due à une diminution de la survie en mer ou par la compétition intra et inter-cohorte des juvéniles qui engendre une mortalité accrue des tacons durant l'hiver précédant la smoltification. Les deux hypothèses sont plausibles pour la population de la Miramichi. Les retours de saumons de la rivière Saint John ont généralement été inférieurs à l'abondance des géniteurs de la cohorte depuis 1972 à 2004. Pour les dernières dix cohortes, la production d'œufs durant la vie entière de la cohorte a été grandement inférieure au niveau de remplacement. Le déclin sévère de la production de saumons sauvages de cette rivière laisse supposer que la mortalité accrue sur ces poissons depuis 1989 pourrait en partie provenir de facteurs en eau douce attribuable à l'environnement associé avec et en amont du barrage Mactaquac. Le pronostic pour cette population dans l'absence d'intervention est pauvre.

INTRODUCTION

The management of Atlantic salmon stocks has for the most part been focused on the regulation of fishing mortality. Despite extensive closures of all the commercial marine and estuarine fisheries in eastern Canada dating from the 1970s and culminating in the complete closure in 2000, stock abundance in many locations has continued to decline and for many stocks, there is little indication of stock recovery in the short or long term.

The catch advice for the management of the homewater and high seas fisheries has been provided on the basis of achieving the conservation objectives of individual rivers and complexes of rivers (ICES 2003). For the high seas fisheries, an alternate objective of achieving at least a 10% increase relative to the average returns during a specified time period was used for the southern regions (Scotia-Fundy and US) (Chaput et al. 2005). The alternate objective was suggested because there was no possibility of achieving the conservation objectives for those areas even in the absence of all fisheries in the high seas and in homewaters. ICES therefore indicated that it would be more useful to consider options for rebuilding the impacted stocks towards the conservation objective. Indeed, the catch advice for homewater and high seas fisheries was formulated with the presumption that stocks in these areas had the potential to rebuild if adequate spawning was provided.

In this document, we compare the stock status and discuss the short term viability and potential for rebuilding of two multi-sea-winter salmon stocks of the Maritime provinces of eastern Canada. We use a series of indicators based on life history characteristics and population dynamics as they relate to variations in abundance. Specifically, we examined:

- changes in age structure including the proportion of returns by maiden age group, and the relative abundance of repeat spawners to maiden fish,
- trends in proportion of eggs coming from maiden fish, 1SW vs 2SW and other age group relative contributions,
- changes in size and proportion female,
- reproductive rates of the stocks over time, and
- stock and recruitment relationships for both stocks.

This leads us to discuss possible factors and life history stages which may be constraining the viability and the rebuilding potential of the stocks.

MATERIALS

Long term data sets from two major Atlantic salmon rivers of eastern Canada are analysed, the Saint John River and the Miramichi River.

The Saint John River is the largest watershed in New Brunswick, flowing in a generally north to south direction and emptying in the outer Bay of Fundy (Fig. 1). An impassable barrier at about 200 km above the head of tide limits access to anadromous salmon to 12.3 million m^2 of salmon production habitat (Marshall and Penny 1983). There is tidal influence as far as 97 km upstream in the main stem and several important tributaries flow into the tidal portion of the main stem of the river. Three hydro-electric dams were constructed on the Saint John River during the 1950s and 1960s culminating in the construction and operation of the lower most dam at Mactaquac. Atlantic salmon destined above Mactaquac Dam are collected at a fish bypass trapping site (Smith 1979). Adult salmon are captured at the trapping site, sampled at a land based sorting facility, and some are selected and retained as broodstock for the hatchery to mitigate for lost production, with the remainder transported and released at various points in the upper portion of the watershed. Salmon sampled at the sorting facility are identified as “wild” or “hatchery origin” fish, measured for length, a portion are scale sampled and weighed and sex determined using external characteristics (Jones et al. 2004). Hatchery returning salmon originate from a smolt release program just below Mactaquac Dam and in the later portion of the time series from fresh water stocking programs at various juvenile life stages. Ages were interpreted from scale samples. River age, total sea age, age at first spawning and ages at subsequent spawnings were recorded from readable scales. The returns to Mactaquac and the ageing time series cover the period 1978 to 2004.

The Miramichi River is located in the eastern and central portion of New Brunswick and flows primarily in an easterly direction to empty into the Gulf of St. Lawrence (Fig. 1). At a total watershed area of 14,000 km², it contains an estimated 54.6 million m² of juvenile rearing area. The river branches off into the Northwest and Southwest Miramichi rivers and water levels are affected by tidal fluctuations as much as 30 km above the confluence of the two branches. Atlantic salmon were captured and sampled at an estuary trapnet in the main portion of the Miramichi River between 1971 and 1992. During 1992 to 2004, trapnets in each of the main branches were operated for sampling the Atlantic salmon runs. The operations, catches, and run-timing at the trapnets have been previously described by Claytor (1996) and Hayward (2001). Salmon sampled at the trapnets are measured for fork length, scale sampled, and sex determined. Until 1994, a subsample of the small salmon (< 63 cm fork length) were sacrificed for detailed sampling of weight, scale sampled and sex determination by dissection. No large salmon (>=- 63 cm fork length) have been sacrificed since 1983. Sex determination by external characteristics is more reliable in the late summer (August) and fall and these form the bulk of the data for sex determination in the last two decades. Scales were interpreted as described for the Saint John River. Returns to the Miramichi River by size group were estimated from mark and recapture experiments between 1985 to 2004, and using assumed efficiency for the main stem trapnet adjusted for harvests in the estuary for the 1971 to 1984 time period (Chaput et al. 2001; Randall et al. 1989).

An index of Atlantic salmon juvenile abundance is available for the Miramichi River. Sampling methods and associations between juvenile indices and egg depositions have been described by Locke et al. (1993) and Chaput et al. (2001). Smolt production estimates from the Northwest Miramichi are available for the years 1999 to 2004 and the method of estimation has been described by Chaput et al. (2002). Juvenile salmon have also been monitored in the Saint John River above Mactaquac and these indices relative to egg depositions have been summarized by Gibson (2006).

METHODS

Age data were used to assign salmon to their year class (year of egg deposition or year of adult return to the river). Year class is the difference between the year of return and the sum of the sea age, freshwater age and unity (to correct for the year of hatch relative to year of spawning). Mean fork lengths and proportion female were estimated for the origin (wild; hatchery), size group (small, large), sea age, spawning history and fresh water age combinations in any given year. The number of eggs per female were calculated from river-specific egg to length fecundity relationships.

$Eggs = 430.14 * e^{0.03605*FL}$ Saint John River (Marshall and Penny 1983)

$Eggs = e^{a*Ln(FL)+b}$ Miramichi River (Randall 1985)

where FL	=	fork length of female in cm
a	=	3.1718 for small salmon (< 63 cm fork length)
	=	1.4132 for large salmon (>= 63 cm fork length)
b	=	-4.5636 for small salmon
	=	2.7560 for large salmon

The number of eggs in the returns and spawners by origin, size group, sea age, spawning history and fresh water age were calculated from the estimated returns by origin and size group, the proportion female in the age group, and the average eggs per female fish of the age group.

Eggs in the returns were lagged to the year class of the spawners to calculate the reproductive rate. Egg production by the year class was calculated as the sum over all returns produced by the year class in subsequent years. The reproductive rate is the ratio of the egg production by returns of the year class to the eggs spawned for the year class. We contrasted the period prior to 1984 with that post-1983 because the management plan of 1984 was intended to increase the spawning escapement to levels at or above conservation. We estimated the egg production by life history groups and focused on the eggs returned in the maiden age groups of the year class and the eggs returned during the entire lifetime of the year class.

RESULTS

The returns of wild multi-sea-winter (MSW) salmon to the Saint John River averaged 5,600 fish between 1978 and 1992 and declined to less than 1,000 fish annually since 1998 (Fig. 2). Returns of wild one-sea-winter (1SW) salmon averaged 6,700 fish between 1978 and 1992 and declined to generally less than 1,000 fish annually since 1997 (Fig. 2). Hatchery origin salmon of both age groups have also declined in abundance despite a relatively constant broodstock collection program and variable hatchery smolt releases ranging between 89,000 and 337,000 fish between 1974 and 2003 (Jones et al. 2004). Returns of hatchery origin 1SW salmon averaged just under 3,000 fish annually between 1978 and 1992 and declined to less than 1,000 fish in 2003. Hatchery MSW salmon returns were as high as 3,000 fish in 1980 but have been less than 1,000 fish annually since 1985 (Fig. 2).

Egg depositions from fish released above Mactaquac and escaping fisheries peaked at about 4 eggs per m² in the late 1970s and have declined almost continually from 1985 to 2004 to reach its lowest level in 2002 (Fig. 3).

Returns of large salmon to the Miramichi River were high during the 1970s, and again in the first half of the 1990s but declined to near record levels in the late 1990s and 2002 (Fig. 4). Small salmon returns were estimated to have been highest in 1986 to 1993 but declined to a record level in 1997 and have been slowly increasing into 2004 (Fig. 4). Egg depositions were highest and well above the conservation requirement in 1986 to 1995 but have since declined and remained below conservation in six of the last nine years with three of the last four years being the years when conservation requirements were met or exceeded (Fig. 3).

Age structure and relative abundance

The Atlantic salmon population in the Miramichi is characterized by an expanding spawning history structure (Table 1). Between 1971 and 1986, there were few repeat spawners in the river with at most two previous spawning migrations. Since 1992 and 1995, adult salmon on their sixth and seventh spawning migrations, respectively, have been sampled in the catches at the estuary trapnets and repeat spawning salmon have comprised 6% to 21% of the total returns of all age groups (Table 1). In the Saint John River, repeat spawners made up as much as 7% of the total returns to the river but this was in the early part of the time series (1970s) and in the last ten years, repeat spawners have represented less than 3% of the total returns with a veritable absence of any salmon beyond a second spawning (Table 2).

For the Miramichi, most of the smolts go to sea after two and three years in river with minimal numbers at four and five years of age (Table 3) (Chaput et al. 2002). The maiden 1SW and 2SW salmon have similar overall proportions of two and three year old smolts but in the repeat spawner groups, there are more 3-year old smolts in the 1SW repeats whereas the 2SW repeats are characterized by a higher proportion of 2-year old smolts (Table 3). Maiden sea ages are dominated by 1SW and 2SW with rare 3SW fish occurrences (Table 3). Within the repeat spawning group, in total since 1971, there are more 1SW repeats on a second migration but 2SW repeats have been more abundant in the third to sixth spawning groups (Table 3).

In the Saint John River, wild salmon are dominated by approximately equal proportions of 2 and 3-year old smolts in the maiden and the repeat spawner components (Table 4). The hatchery smolt rearing program produced two-year smolts prior to 1985 and one-year old smolts from 1985 to the present. The resulting returns of hatchery fish are predominantly one and two-year old smolts for both the 1SW and 2SW components (Table 4). There are higher proportions of 2-year old smolts in the repeat spawner groups which reflects the higher abundance of repeats during 1978 to 1985 corresponding to the period of 2-year old smolt production program.

As the repeat spawner abundance has increased in the Miramichi, the number of year classes present in the annual spawning migration has increased from four to five in the 1970s to as many as eight to nine year classes in the returns of the 1990s (Table 5). This contrasts with the Saint John River stock where for either wild salmon or hatchery origin salmon, there has been no change in the number of year classes over time, with generally five year classes present, with a maximum of seven in the earlier portion of the time series (Table 5). This is consistent with the lower abundance of repeat spawners in the Saint John relative to the Miramichi.

Reproductive rate

For the Miramichi River, the wild salmon stock produced maiden fish recruitment surplus to spawners for most year classes between 1971 and 1989 but was consistently below replacement for the 1990 to 1997 year classes (Fig. 5). The eggs in the maiden returns of the 1998 year class are estimated to have been equivalent to the eggs which were spawned. An examination of the spawners to recruitment plot suggests that for the Miramichi, there was a greater chance (9 of 11 events) that the recruitment would be less than the spawners when egg depositions exceeded the conservation requirement of 132 million eggs than when egg depositions were less than conservation (Fig. 6).

For the Saint John River, wild salmon production varied around the replacement line for the 1972 to 1988 year classes but plummeted and remained well below replacement for the 1989 to 1999 year classes (Figs. 7, 8). There are so few repeat spawners in this stock that the differences between the lifetime production of eggs and egg production from maiden spawners are minimal. An examination of the spawners to recruitment plot indicates that the population was fluctuating about the replacement line but egg to maiden salmon mortality increased substantially and remained high for the 1989 and subsequent year classes (Fig. 6). Reproductive rates for the hatchery origin salmon were relatively constant for the 1985 to 1999 year classes (Fig. 7).

Egg production by sea age

There has been an important change in the proportion of the eggs produced by age group in the lifetime of the year class of salmon of the Miramichi River (Fig. 9). There has been an increase in the 1SW maiden contribution but the largest change has been from the contribution of repeat spawners. For the 1981 and subsequent year classes, the egg production from MSW maiden salmon amounts to about 50% of the lifetime production of the year class. The decline from the previous time period is attributable to a decline in 2SW maiden salmon abundance and an increase in the repeat spawner abundance. This contrasts with the Saint John River stock in which the MSW maiden salmon continue to contribute over 80% of the eggs in the lifetime of the year class with a slight decline for the recent three year classes (Fig. 10). In the hatchery origin salmon, 1SW maiden salmon can contribute as much as 25% of the eggs during the life time of the cohort and this has increased for the post 1989 year classes (Fig. 10).

Other stock characteristics

The mean lengths of 1SW and 2SW female maiden salmon from the Miramichi River have increased over the past thirty years (Fig. 11). Mean lengths of 1SW maiden salmon in the recent five years are 7% greater than the first ten years of the time series, while 2SW salmon mean lengths increased by 4%. The estimated fecundity has also increased; 1SW maiden salmon fecundity is 25% greater in the last five years compared to the first ten years and 2SW salmon fecundity is 6% greater (Fig. 11). The proportion female has not changed over time in either the 1SW or 2SW maiden salmon components (Fig. 12).

In the Saint John River stock, there are important annual variations in mean length. Although the Saint John River stock has on average larger 1SW maiden salmon compared to the Miramichi, there was no increase over time as observed for the Miramichi, (Fig. 13). Fecundity as well has not increased over time nor is there any important change in the proportion female fish in the maiden spawning components (Fig. 12).

Return rates at sea

Salmon from the Miramichi return to a second spawning as consecutive or alternate spawners. Return rates of 1SW maiden salmon are lower than those of 2SW maiden salmon (Fig. 14). Return rates are not corrected for inriver fisheries removals which accounts for some of the differences between the two age groups. Returns rates of 2SW salmon have increased over the time period of study and for some year classes, have exceeded 25% (Fig. 14). There has been an increase in the return rate of 1SW and 2SW salmon as consecutive spawners and this spawning life history has exceeded the alternate repeat spawner life history for five of the last seven year classes (Fig. 14). Return rates to subsequent spawnings are high but variable, varying between 20% and 60% for several year classes in the time series (Fig. 14).

The Saint John River salmon have low return rates to subsequent spawnings, have declined over time, and the alternate spawner life history remains dominant (Fig. 15). Generally less than 5% of the maiden 1SW and 2SW salmon return to spawn a second time.

Return rates of 1-year old hatchery smolts to the Saint John River are less than 1% while return rates to 2SW salmon have been less than 0.5% since the 1984 smolt release (Fig. 16). The return rates of wild smolts from the Nashwaak River, a tributary of the Saint John River immediately below the furthest downstream hydro-dam, have varied from 1.5% to 6.4% for 1SW salmon and from 0.3% to 1.3% for 2SW salmon. We assume that wild smolts from the Saint John River above Mactaquac Dam which manage to pass safely through the hydro dams should have similarly higher return rates than hatchery smolts (Fig. 16).

CONSTRAINTS TO VIABILITY AND REBUILDING

The reproductive rate calculations indicate that the Miramichi River population had the potential historically to produce a surplus of maiden egg production. In the recent decade, maiden egg production has been less than the eggs which produced them during a time period when egg depositions exceeded the conservation requirement. With a decline in egg depositions, the eggs in the returns of maiden fish have exceeded the eggs from the parental stock and the potential for increased returns appears feasible.

The decline in 1SW and 2SW maiden salmon abundance may have been partly the result of high egg depositions for those year classes resulting in over-compensatory density dependent response in freshwater. Freshwater conditions have remained suitable for the survival of high numbers of juveniles from fry to age-1 parr and from age-1 parr to age-2 parr (Fig. 17). Since 1999, smolt production from the Northwest Miramichi, one of the two main branches, has been estimated to range from 162 to 390 thousand, a production rate of 1 to 2.3 smolts per 100 m^2 of rearing habitat area (Chaput et al. 2002). This is less than expected given one-year old and two-year old parr densities ranging between 30 and 47 fish per 100 m^2 (Fig. 17).

There is a negative association between the mean biomass of juveniles of the year and the smolt production the following spring (Fig. 17). The total biomass of juveniles at the monitored sites in the Northwest Miramichi has averaged 230 to 377 grams per 100 m^2 in the years prior to the smolt emigration year, 1998 to 2003. The true dynamic is not well defined because there are no observations for lower biomass levels but the parr age-1 index plotted against the returns of maiden 1SW and 2SW salmon adjusted to the year of the parr index suggests an over-compensatory relationship in salmon production for the Miramichi. An examination of the spawners to recruitment plot from Figure 6 indicates as well that there is a greater chance (9 of 11 events) that the recruitment will be less than the spawners when egg depositions exceed 150 million eggs (equivalent to 2.7 eggs per m^2) than when egg depositions were less than 150 million.

The conclusions about the role of the freshwater over-compensatory factors in conditioning the dynamic of salmon abundance in the Miramichi must be tempered by the reality that the stock and recruitment dynamic on the Miramichi could also be explained by a change in marine survival. An alternate hypothesis would be that adult production would level off at high egg deposition and high juvenile production and that the dynamic observed in the Miramichi is the result of an important decline in the sea survival of salmon in the past 15 years. There are indications from monitored wild stocks in eastern Canada that return rates have been lower in this recent time period relative to the historical values (O'Connell et al. 2006). As well, the return rates of hatchery released smolts at Mactaquac are much lower post 1985 than prior to that time period. Chaput et al. (2005) describe two phases of 2SW salmon production from eastern Canada with a change in relative production post 1988 or 1989. The negative relationship between smolt production and biomass of juveniles however suggests that the lower abundance of salmon in recent years is not likely entirely due to marine factors.

The prognosis for the Miramichi remains positive. Marine return rates of 1SW and 2SW maiden salmon appear to be sufficient in recent years to replace the eggs which produced them, at least when egg depositions were below 150 million eggs. Size at age has increased such that every female now has the potential to produce more eggs, there is a high survival to second and third spawning, and juvenile production remains high. The outstanding question is whether intra and inter-cohort competition of the juveniles is resulting in density dependent mortality of parr in the winter prior to smolting as seems to be indicated by the short time series available for the Miramichi.

The Saint John River population has generally been in decline throughout the time series. For the last ten year classes, the eggs in the returns of maiden salmon have been substantially below the eggs spawned. The dramatic decline in the reproductive rate of wild salmon strongly suggests that the increased mortality on the wild salmon post 1989 may in part be driven by a freshwater constraint associated with the environment at and above Mactaquac. The hatchery program has generally maintained a surplus production of eggs in the returns of hatchery origin salmon and the relative rate of production has been fairly constant and positive since the 1985 year class. The majority of the hatchery origin salmon are from smolt releases just below Mactaquac Dam and we would have expected these fish to have been exposed to the same marine mortality factors which wild smolts and salmon would have encountered.

Hydro dams and their resulting environment are not the only cause of the decline of the wild salmon from the Saint John River. The status of the Nashwaak River stock has also declined dramatically in synchrony with the stock of the Saint John River. The Nashwaak population is not affected by hydro-dams directly, has had minimal hatchery intervention but the estimated egg depositions have been 7% to 43% of the conservation requirements during 1993 to 2003. These levels are similar to those achieved in the Saint John River from both wild and hatchery origin salmon but are better than the levels achieved by wild salmon alone (Jones et al. 2004). In contrast to the Miramichi, for the Saint John River, there are no positive changes in life history characteristics (increased size at age or proportion female, decreased survival of previous spawners) of salmon which could partially compensate for the reduced smolt and repeat spawner survivals in this population. Even at low population abundance, recruitment has been insufficient to replace the parental stock and abundance is largely now constrained by low parental stock and poor density independent survival.

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Table 1. Estimated annual abundance of maiden (0 previous spawnings) and repeat spawner Atlantic salmon by number of previous spawnings for the Miramichi River.

	Number of previous spawnings							Total	Percent
Year	0	1	2	3	4	5	6	Abundance	Repeat
1971	58,676	1,326	78					60,080	2.3%
1972	74,053	1,271						75,324	1.7%
1973	71,129	608						71,737	0.8%
1974	112,893	2,914	203					116,010	2.7%
1975	90,170	3,379	170					93,719	3.8%
1976	91,696	21,875	810					114,381	19.8%
1977	76,232	1,843	1,510					79,585	4.2%
1978	45,559	3,221						48,780	6.6%
1979	57,453	2,193	373					60,019	4.3%
1980	75,909	1,445	552					77,906	2.6%
1981	76,883	2,597	1,975					81,455	5.6%
1982	105,022	5,408	707					111,137	5.5%
1983	48,957	4,151						53,108	7.8%
1984	43,267	1,419		158				44,844	3.5%
1985	60,916	19,579	1,043					81,538	25.3%
1986	144,318	4,186	330					148,834	3.0%
1987	100,538	3,391	308					104,237	3.5%
1988	139,750	3,131	522	261				143,664	2.7%
1989	86,096	4,766	1,497	83				92,442	6.9%
1990	101,457	7,767	2,351	499				112,074	9.5%
1991	79,153	7,177	2,835	1,684				90,849	12.9%
1992	177,553	5,797	3,895	1,857	408	91		189,600	6.4%
1993	119,323	5,648	3,194	1,631	204			130,000	8.2%
1994	60,539	2,719	714	399	84	63		64,517	6.2%
1995	74,015	3,235	752	357	56	38	19	78,473	5.7%
1996	46,456	3,992	1,131	371	37	56		52,043	10.7%
1997	26,047	4,098	1,609	667	78	26	13	32,538	19.9%
1998	29,861	4,902	2,128	842	117	23	23	37,896	21.2%
1999	31,283	3,442	1,528	724	181	40		37,199	15.9%
2000	40,557	4,104	1,601	904	311	30	15	47,523	14.7%
2001	42,610	4,885	1,194	630	296	57	19	49,691	14.2%
2002	50,731	2,797	948	414	360	53	13	55,317	8.3%
2003	42,849	4,671	1,206	572	164	143	20	49,625	13.7%
2004	58,483	5,439	1,575	536	134	17	17	66,201	11.7%

Table 2. Estimated annual abundance of maiden (0 previous spawnings) and repeat spawner Atlantic salmon by number of previous spawnings for the Saint John River.

	Number of previous spawnings				Total	Percent
Year	0	1	2	3	abundance	Repeat
1978	11,132	348	21		11,501	3.2%
1979	13,674	855	56	12	14,597	6.3%
1980	31,895	1,104	117	74	33,191	3.9%
1981	20,046	635	22	32	20,735	3.3%
1982	14,407	1,000	77	26	15,509	7.1%
1983	12,674	332			13,006	2.5%
1984	20,325	331			20,656	1.6%
1985	19,516	307	32		19,855	1.7%
1986	14,850	820	20		15,691	5.4%
1987	13,690	377	2		14,069	2.7%
1988	13,534	164	19		13,717	1.3%
1989	15,151	236	15		15,402	1.6%
1990	12,392	295	13		12,700	2.4%
1991	13,575	294	16		13,886	2.2%
1992	13,654	134			13,788	1.0%
1993	7,637	115			7,752	1.5%
1994	5,774	102	5		5,881	1.8%
1995	7,259	68	1		7,328	0.9%
1996	9,925	106			10,031	1.1%
1997	5,099	127			5,226	2.4%
1998	5,779	166	4		5,949	2.9%
1999	5,025	36			5,061	0.7%
2000	3,565	47			3,612	1.3%
2001	2,873	33			2,906	1.1%
2002	2,699	34	1		2,734	1.3%
2003	2,033	20			2,053	1.0%
2004	2,190	9			2,199	0.4%

Table 3. Age characteristics of Atlantic salmon from the Miramichi River for the period 1971 to 2004.

Number of previous spawnings	Sea age at first spawning	Percent by river age			
		2	3	4	5
0	1	41.6%	56.6%	1.8%	0.0%
	2	46.2%	53.0%	0.7%	0.0%
	3	51.4%	43.0%	5.6%	0.0%
1	1	39.3%	57.0%	3.7%	
	2	56.9%	40.9%	2.2%	
	3	97.1%	2.9%	0.0%	
2	1	39.8%	59.8%	0.4%	
	2	65.2%	34.5%	0.3%	
	3	79.0%	21.0%	0.0%	
3	1	42.6%	57.4%	0.0%	
	2	61.9%	37.6%	0.5%	
4	1	35.6%	64.4%		
	2	61.8%	38.2%		
5	1	50.3%	49.7%		
	2	66.1%	33.9%		
6	1				
	2	100.0%	0.0%		

Number of previous spawnings	Percent by sea age at first spawning		
	1	2	3
0	74.8%	25.1%	0.1%
1	55.2%	44.3%	0.5%
2	24.3%	75.4%	0.3%
3	16.3%	83.7%	
4	22.2%	77.8%	
5	7.7%	92.3%	
6		100.0%	

Table 4. Age characteristics of Atlantic salmon from the Saint John River at Mactaquac for the period 1978 to 2004.

Hatchery origin salmon						
Number of	Sea age at	Percent by river age				
previous spawnings	first spawning	1	2	3	4	5
0	1	46.9%	42.4%	10.0%	0.7%	0.0%
	2	45.0%	49.3%	5.5%	0.1%	
	3	25.3%	63.2%	11.4%		
1	1	13.7%	81.2%	5.0%		
	2	33.9%	61.6%	2.3%		
2	1	50.0%	50.0%			
	2	13.9%	86.1%			
3	1	0.0%	100.0%			

Wild salmon						
Number of	Sea age at	Percent by river age				
previous spawnings	first spawning	1	2	3	4	5
0	1		46.6%	49.9%	3.3%	0.1%
	2		49.4%	48.7%	1.9%	0.0%
	3		43.6%	56.4%		
	4		8.6%		91.4%	
1	1		48.2%	49.3%	2.5%	
	2		62.5%	35.7%	1.8%	
	3		100.0%			
2	1		52.9%	47.1%		
	2		44.1%	55.9%		
	3		98.3%	1.7%		
3	1					
	2		17.4%	82.6%		

Hatchery origin salmon				
Number of	Percent by sea age at first spawning			
previous spawnings	1	2	3	4
0	74.7%	25.3%	0.0%	
1	67.9%	32.1%		
2	5.3%	94.7%		
3	100.0%			

Wild origin salmon				
Number of	Percent by sea age at first spawning			
previous spawnings	1	2	3	4
0	56.1%	43.7%	0.2%	0.0%
1	50.7%	48.7%	0.6%	
2	16.8%	67.6%	15.5%	
3		100.0%		

Table 5. Number and range of year classes present in the annual returns of Atlantic salmon to the Miramichi River and to the Saint John River (wild, hatchery origin), 1971 to 2004.

	Miramichi			Saint John wild salmon			Saint John hatchery salmon		
Year of Return	Year classes present Total	Range		Year classes present Total	Range		Year classes present Total	Range	
1971	5	1963	1967						
1972	5	1964	1968						
1973	5	1965	1969						
1974	5	1966	1970						
1975	7	1965	1971						
1976	6	1967	1972						
1977	5	1969	1973						
1978	5	1970	1974	5	1970	1974	5	1971	1975
1979	6	1970	1975	7	1969	1975	6	1971	1976
1980	6	1971	1976	5	1972	1976	5	1972	1977
1981	5	1971	1977	7	1971	1977	6	1972	1978
1982	6	1973	1978	7	1972	1978	3	1976	1979
1983	5	1975	1979	5	1975	1979	4	1977	1980
1984	5	1976	1980	5	1976	1980	5	1977	1981
1985	6	1975	1981	5	1977	1981	4	1979	1982
1986	7	1976	1982	5	1978	1982	4	1980	1983
1987	6	1978	1983	6	1978	1983	5	1980	1984
1988	8	1976	1984	7	1978	1984	4	1982	1985
1989	8	1977	1985	6	1980	1985	6	1981	1986
1990	8	1979	1986	5	1982	1986	7	1979	1987
1991	8	1980	1987	5	1983	1987	6	1982	1988
1992	8	1981	1988	5	1984	1988	4	1986	1989
1993	7	1983	1989	5	1985	1989	5	1986	1990
1994	8	1983	1990	5	1986	1990	4	1988	1991
1995	9	1983	1991	5	1987	1991	5	1988	1992
1996	8	1985	1992	5	1988	1992	5	1989	1993
1997	9	1985	1993	5	1989	1993	5	1990	1994
1998	8	1987	1994	6	1989	1994	6	1990	1995
1999	8	1988	1995	5	1991	1995	5	1992	1996
2000	8	1989	1996	5	1992	1996	5	1993	1997
2001	9	1989	1997	5	1993	1997	4	1995	1998
2002	9	1990	1998	5	1994	1998	4	1996	1999
2003	9	1991	1999	5	1995	1999	4	1997	2000
2004	8	1993	2000	4	1997	2000	4	1998	2001

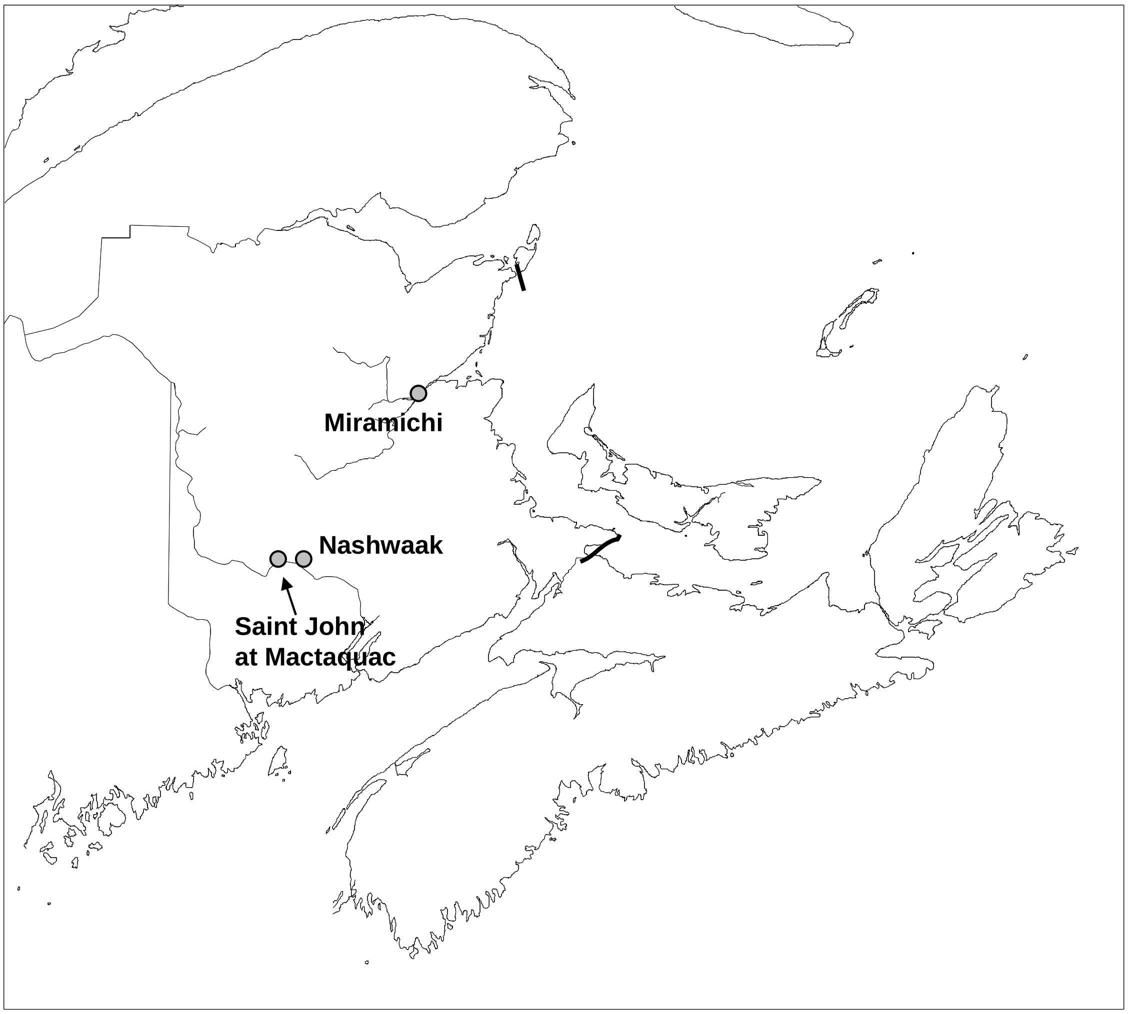


Figure 1. Location of the Saint John River, Nashwaak River, and Miramichi River in the Maritime provinces of eastern Canada.

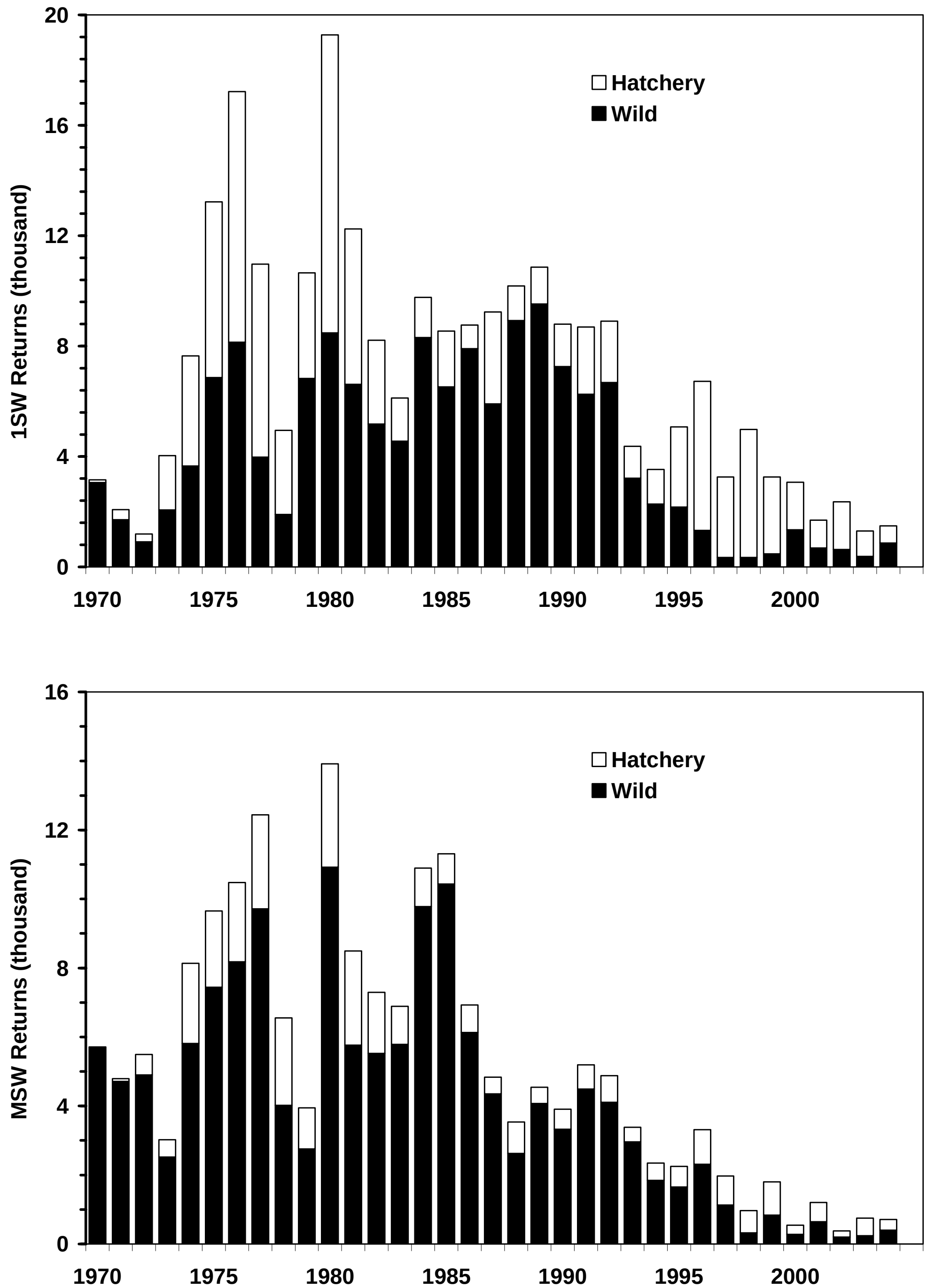


Figure 2. Returns by wild and hatchery origin of 1SW and MSW salmon to Mactaquac on the Saint John River, 1970 to 2004.

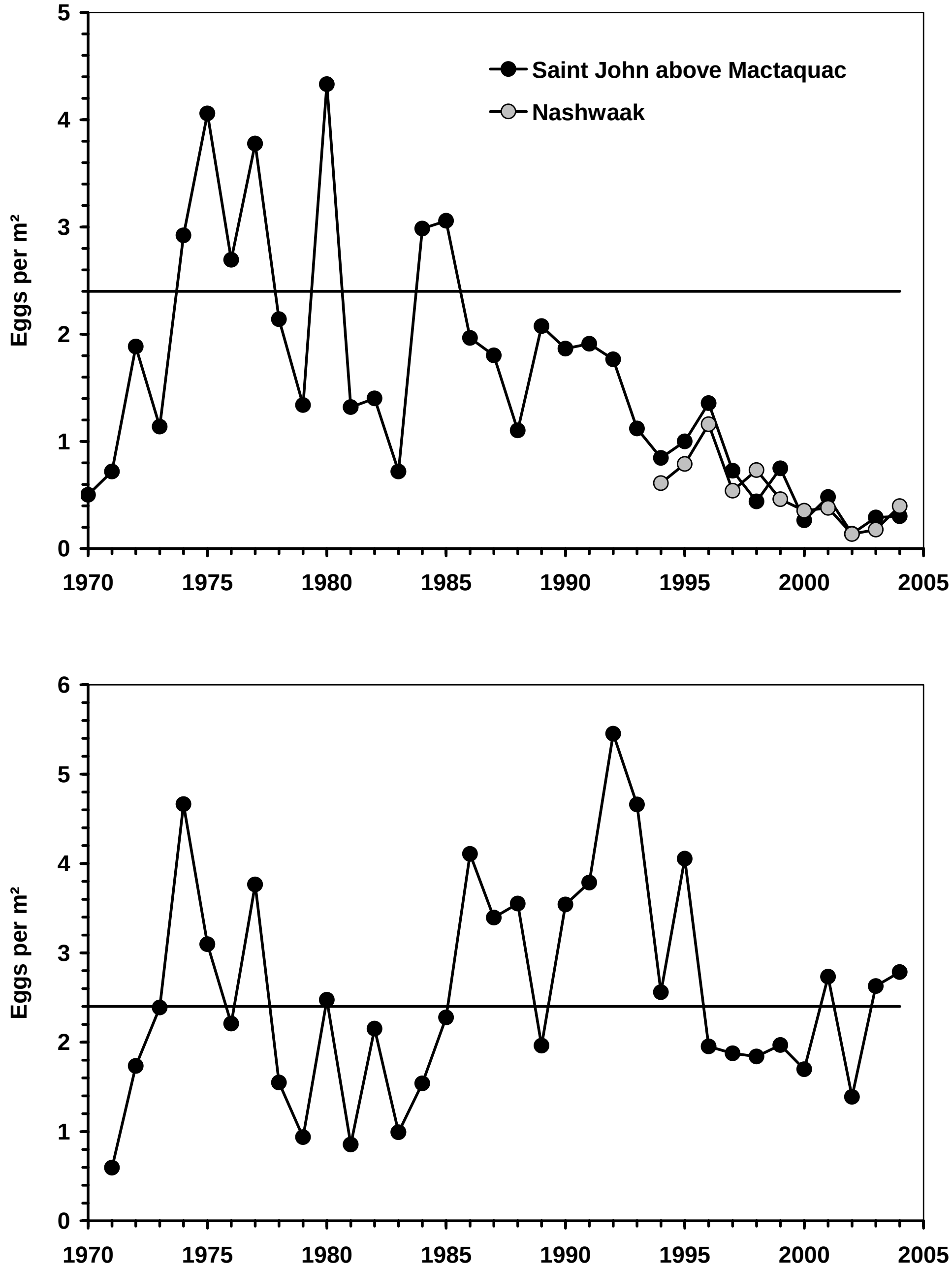


Figure 3. Estimated egg depositions, expressed as eggs per m² of juvenile rearing habitat, for the Saint John River above Mactaquac (from hatchery and wild salmon combined) and the Nashwaak River (upper panel) and for the Miramichi River (lower panel). The conservation requirement is 2.4 eggs per m² (horizontal line).

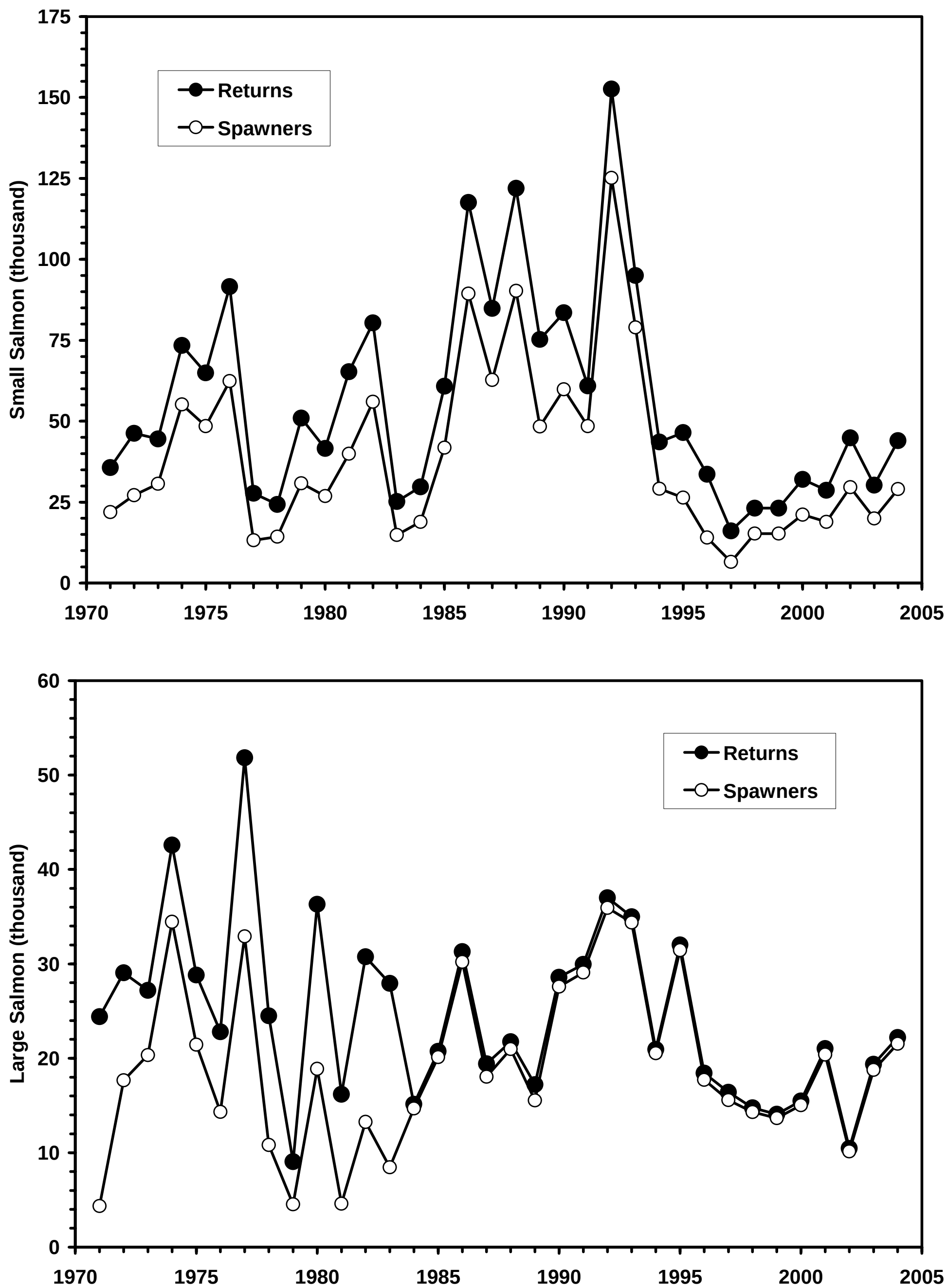


Figure 4. Small salmon (<63 cm fork length; upper panel) and large salmon (>= 63 cm fork length; lower panel) returns and spawners to the Miramichi River, 1971 to 2004.

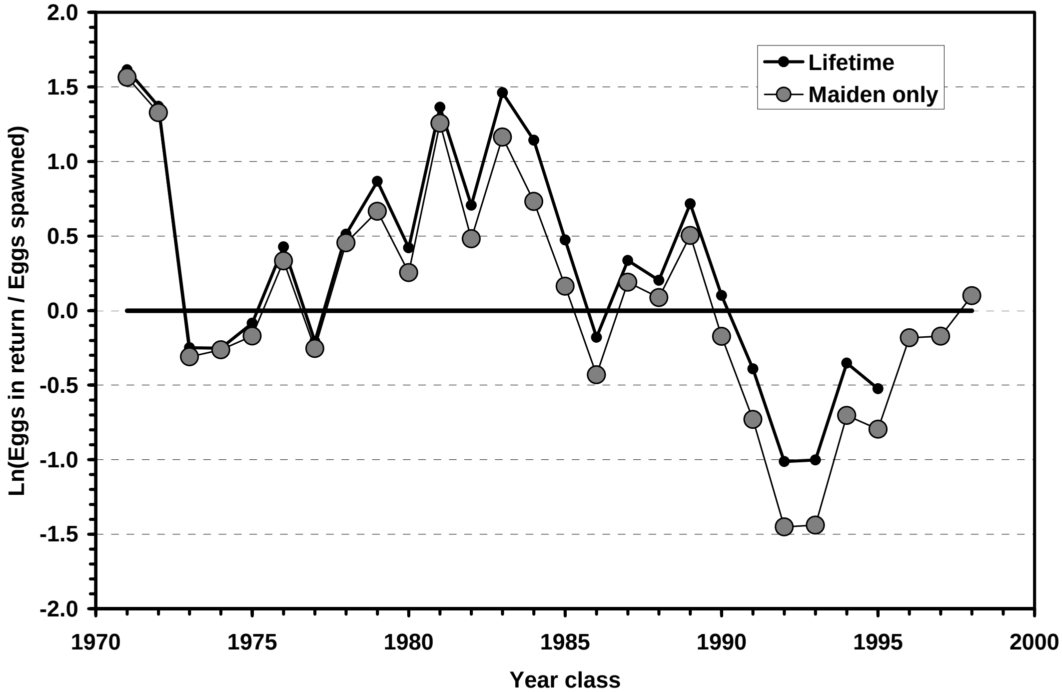


Figure 5. Natural logarithm of the reproductive rate (eggs in returns / eggs spawned) by year class for salmon from the Miramichi River. Negative values indicate that there were fewer eggs in the total returns than were spawned to produce them. Maiden only refers to eggs in the returns as maiden spawners only. Lifetime eggs refers to eggs in the returns as maiden and repeat spawners.

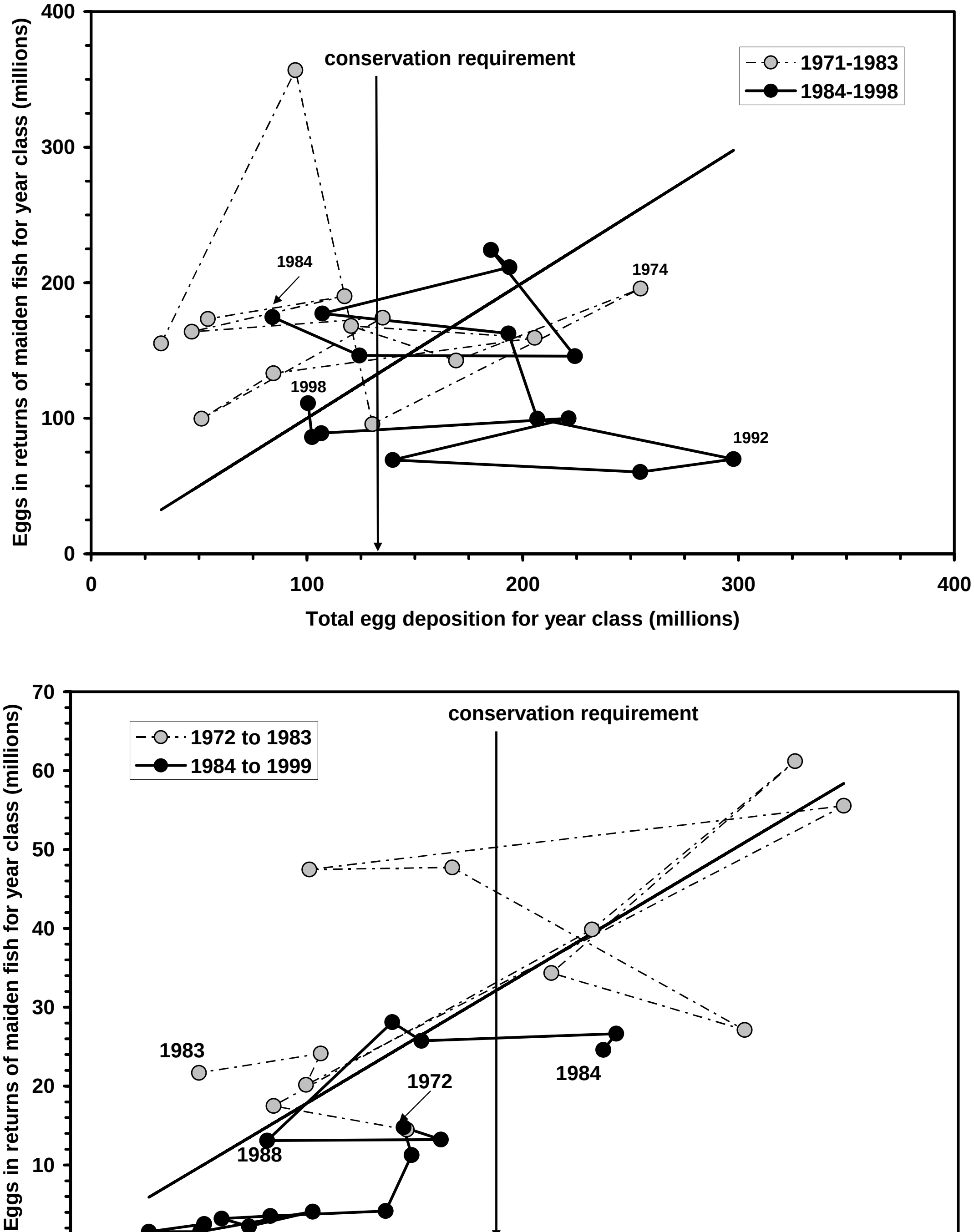
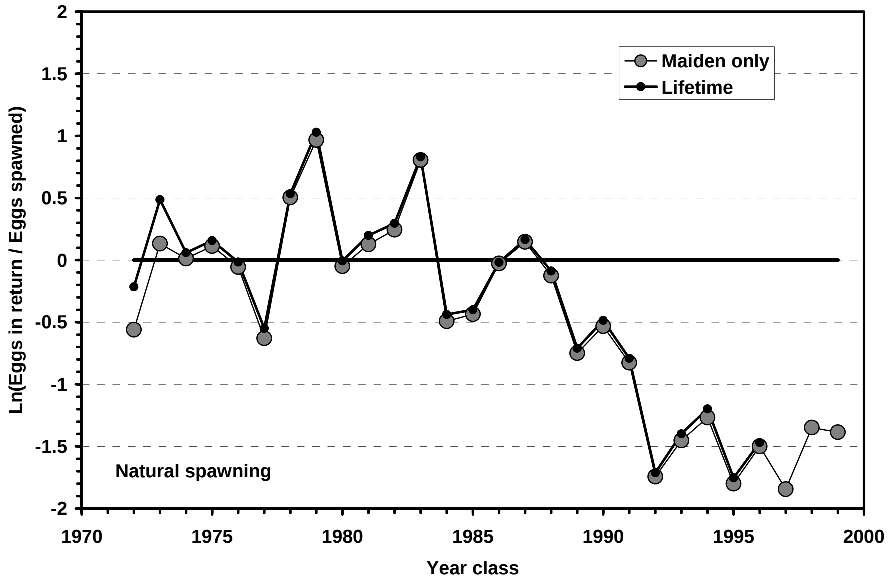


Figure 6. Scatter plots of the annual egg deposition versus the eggs in the returns as maiden salmon by year class for the Miramichi River (upper panel) and the Saint John River above Mactaquac (lower panel). The diagonal line is the equivalence line where one egg is returned for one egg spawned.



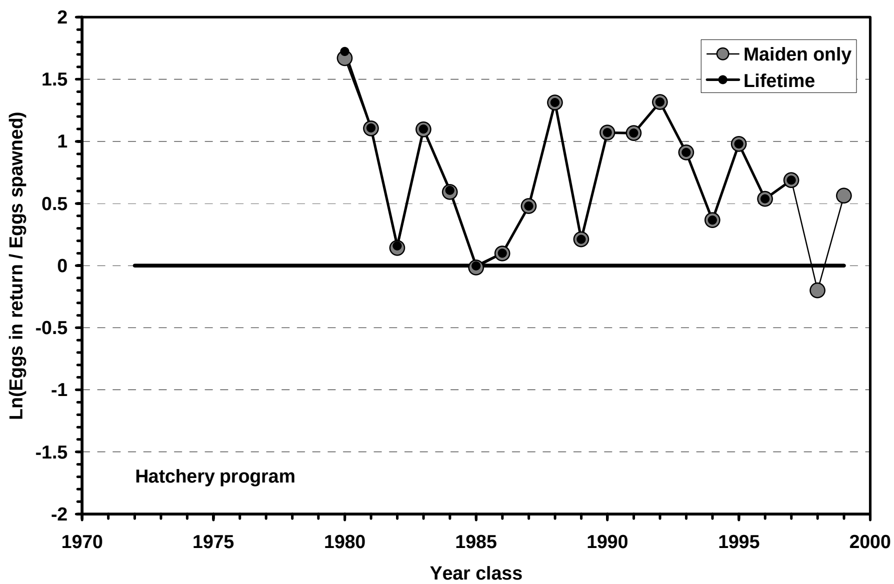


Figure 7. Natural logarithm of the reproductive rate (eggs in returns / eggs spawned) by year class for salmon from the Saint John River at Mactaquac (wild in the upper panel, hatchery origin in the lower panel). Negative values indicate that there were fewer eggs in the total returns than were spawned to produce them. Maiden only refers to eggs in the returns as maiden spawners. Lifetime eggs refers to eggs in the returns as maiden and repeat spawners.

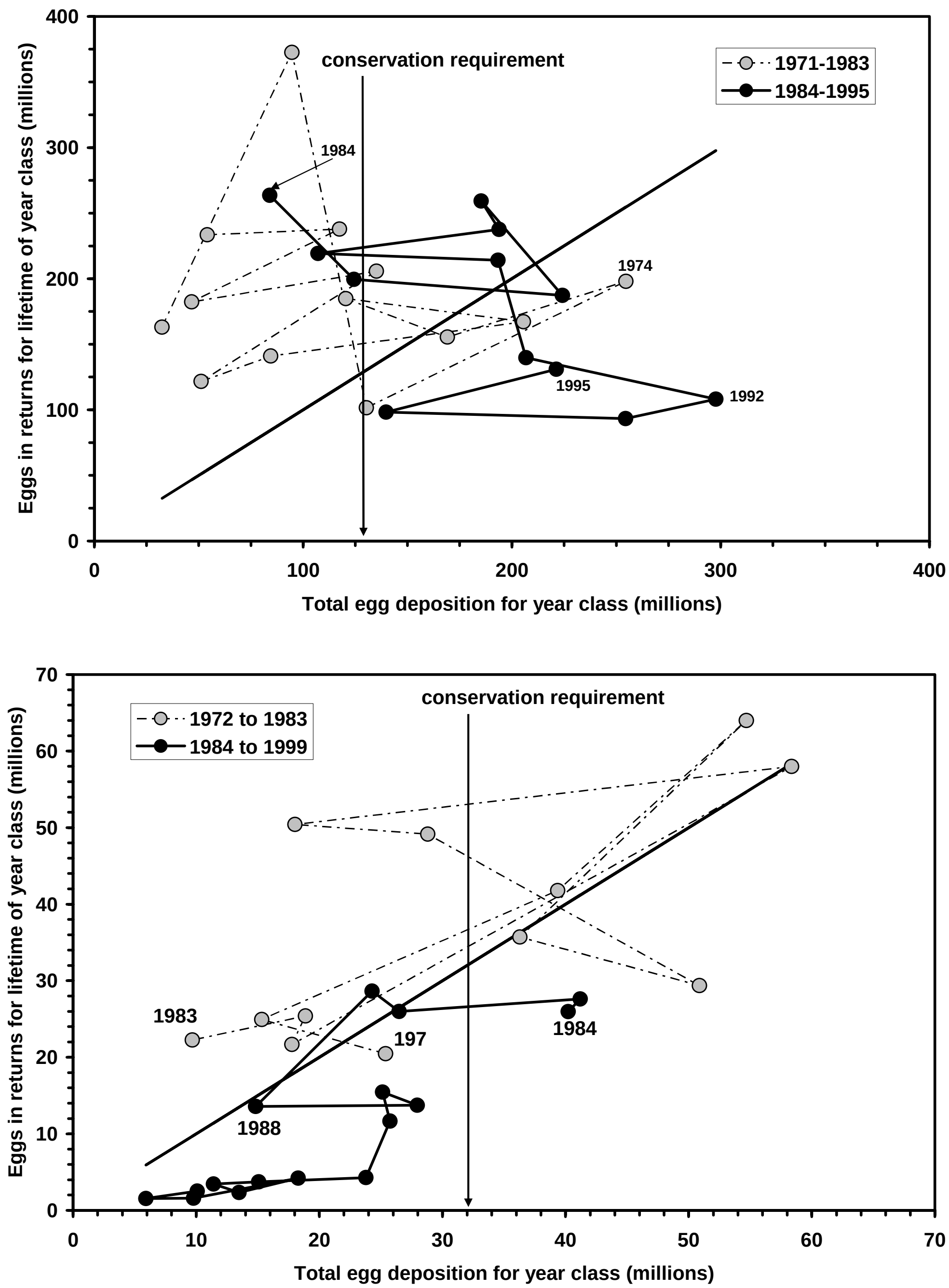


Figure 8. Scatter plots of the annual egg deposition versus the eggs in the returns for the lifetime of the cohort (as maiden salmon and repeat spawners) by year class for the Miramichi River (upper panel) and the Saint John River above Mactaquac (lower panel). The diagonal line is the equivalence line where one egg is returned for one egg spawned.

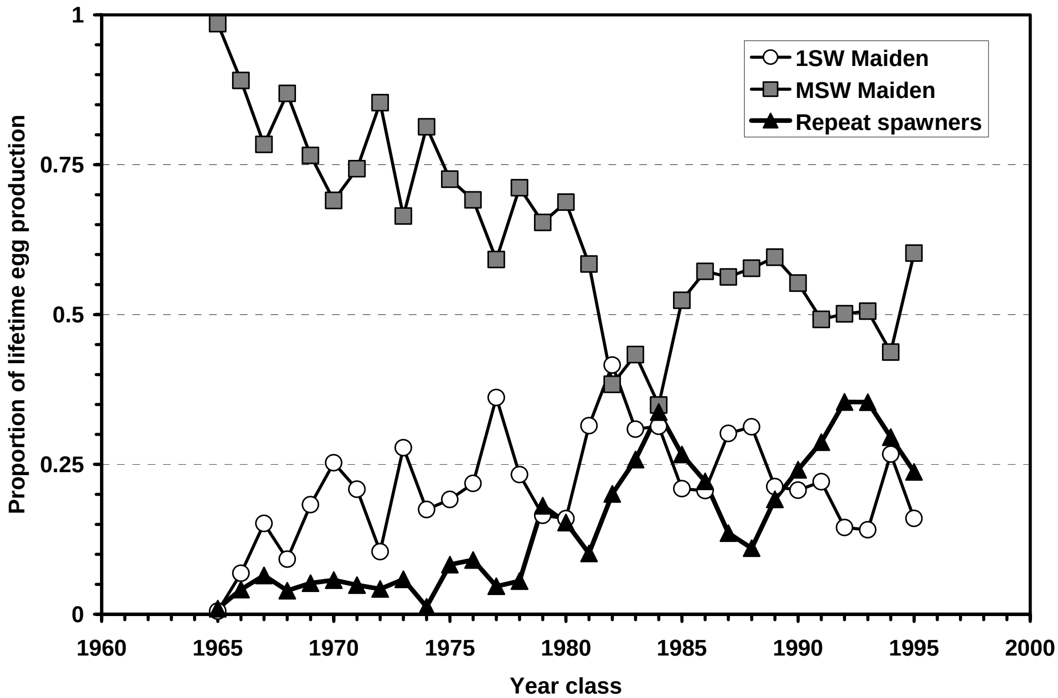


Figure 9. Proportion by 1SW maiden, MSW maiden, and repeat spawners of the lifetime egg production by year class in the returns of wild salmon to the Miramichi River.

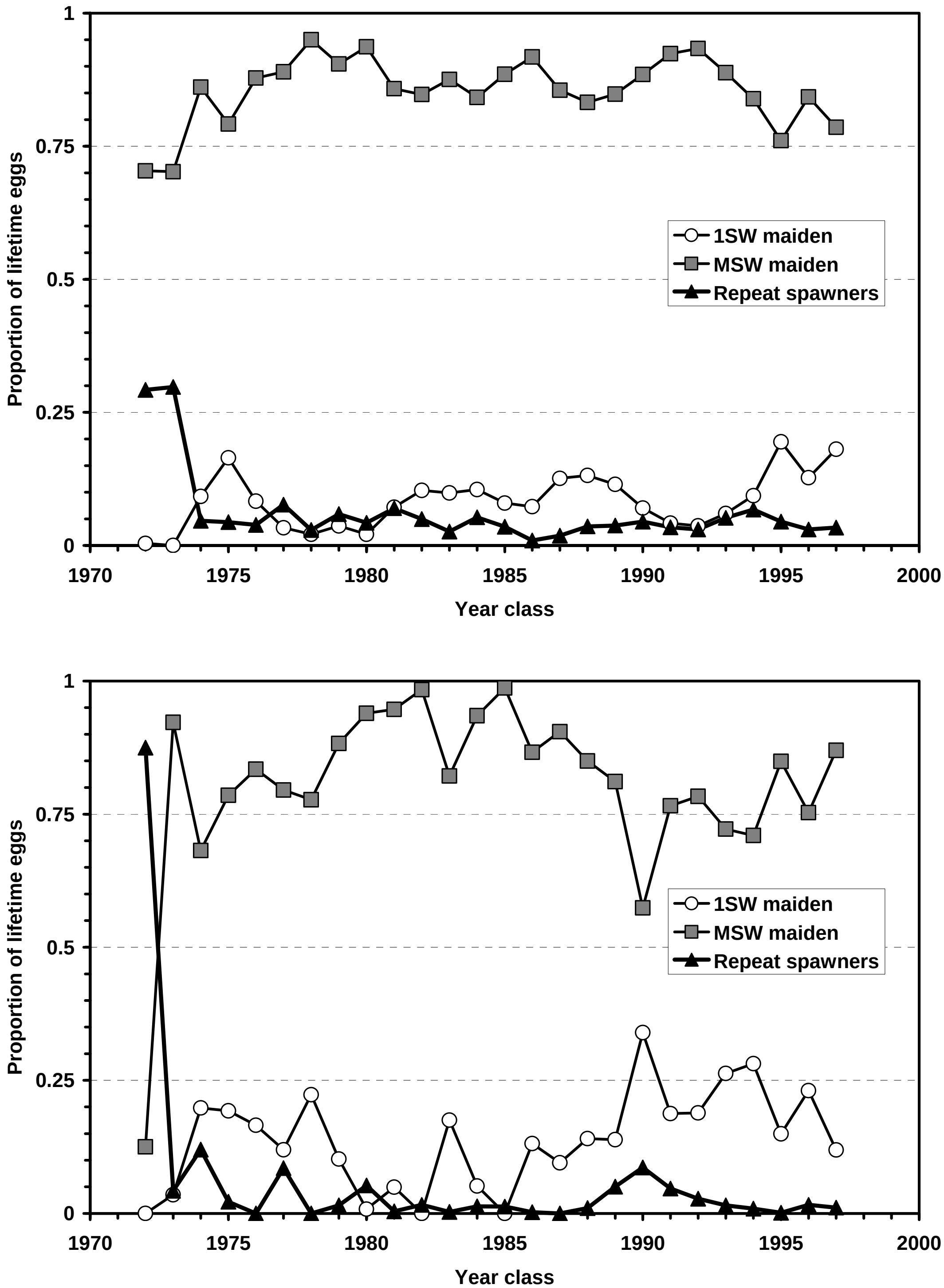


Figure 10. Proportion by 1SW maiden, MSW maiden, and repeat spawners of the lifetime egg production by year class in the returns to the Saint John River for wild salmon (upper) and hatchery origin salmon (lower).

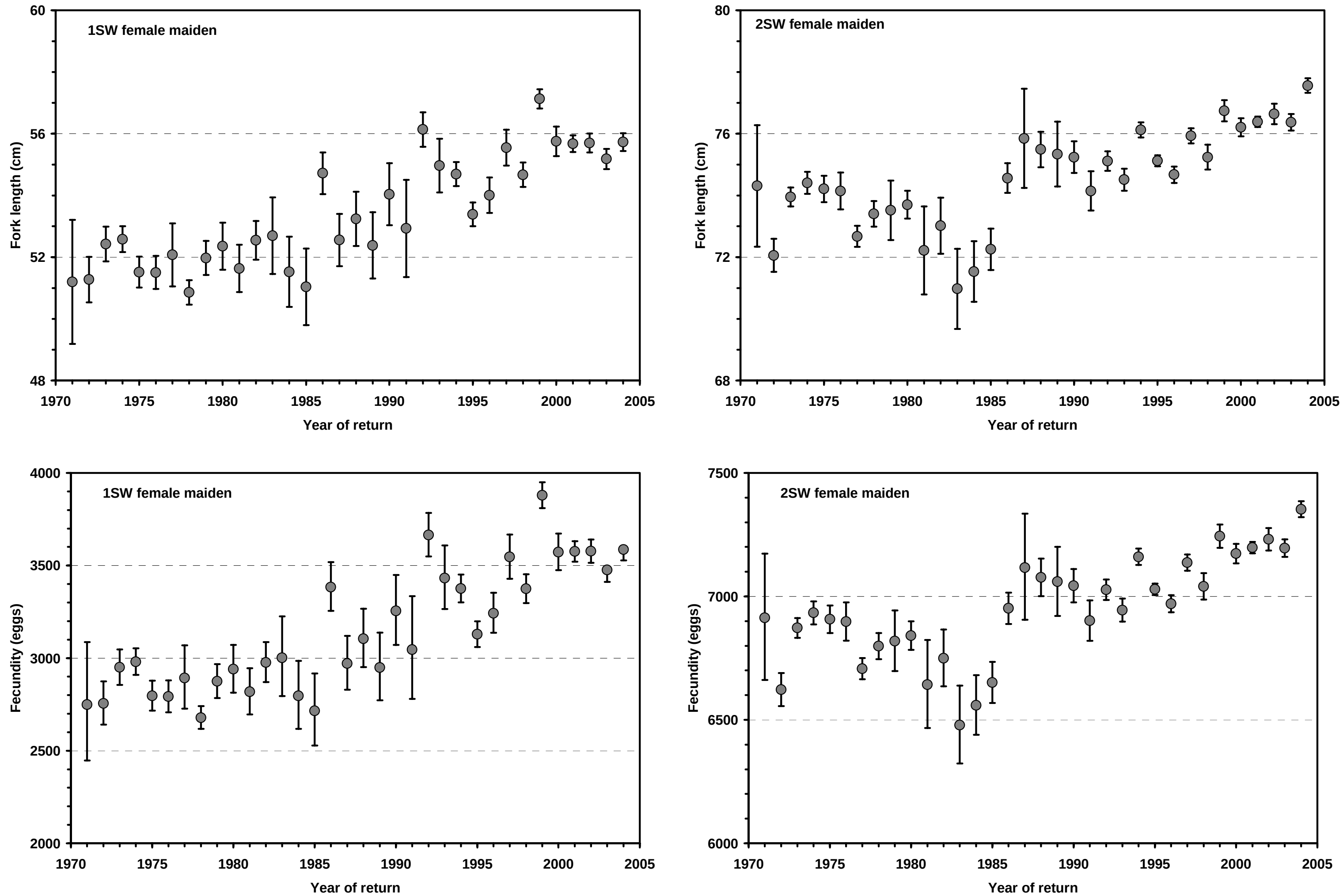


Figure 11. Changes in mean fork length (upper panels) and fecundity (lower panels) of female 1SW (left) and 2SW (right) maiden wild salmon for the Miramichi River. Mean +/- 2 standard error bars are shown.

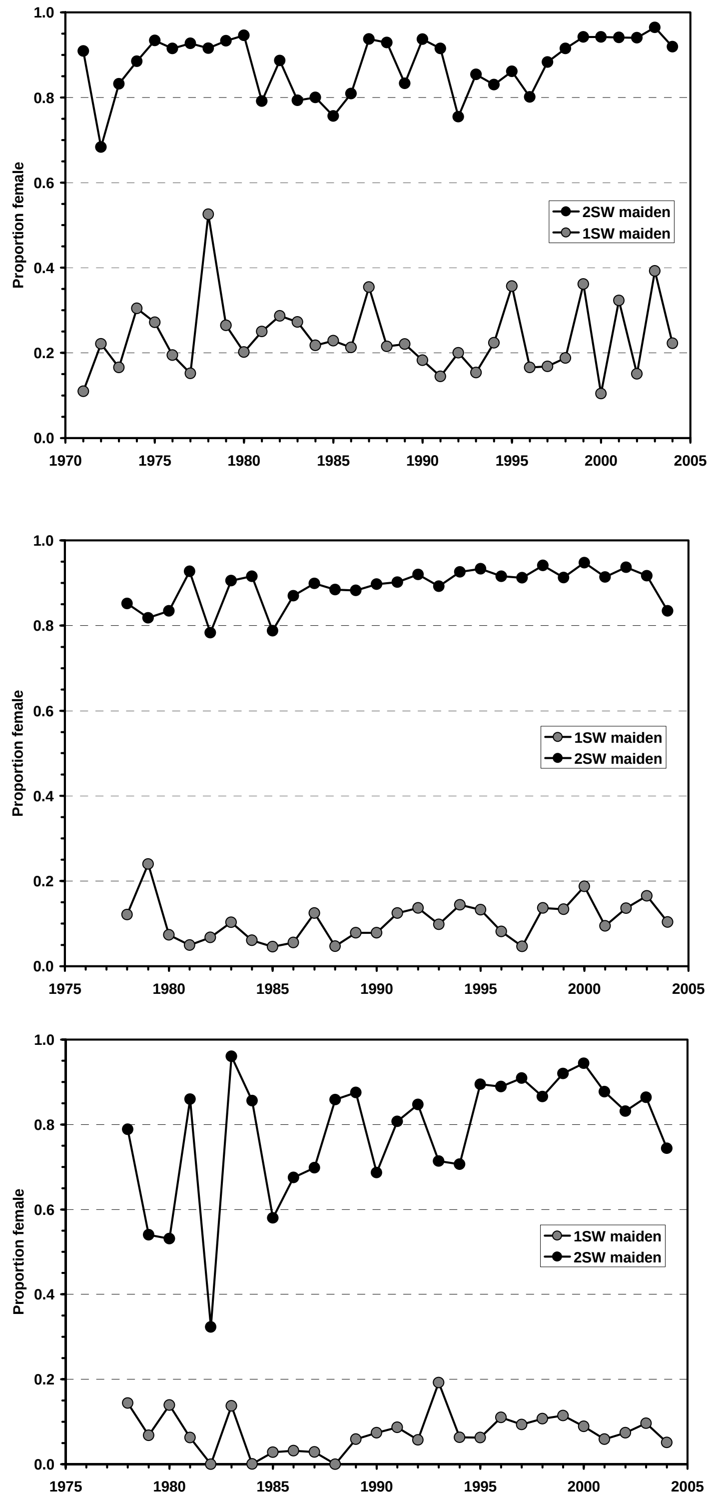


Figure 12. Proportion female in 1SW maiden and 2SW maiden age groups from the Miramichi River wild salmon (top), Saint John River wild salmon (middle), and Saint John River hatchery origin salmon (bottom).

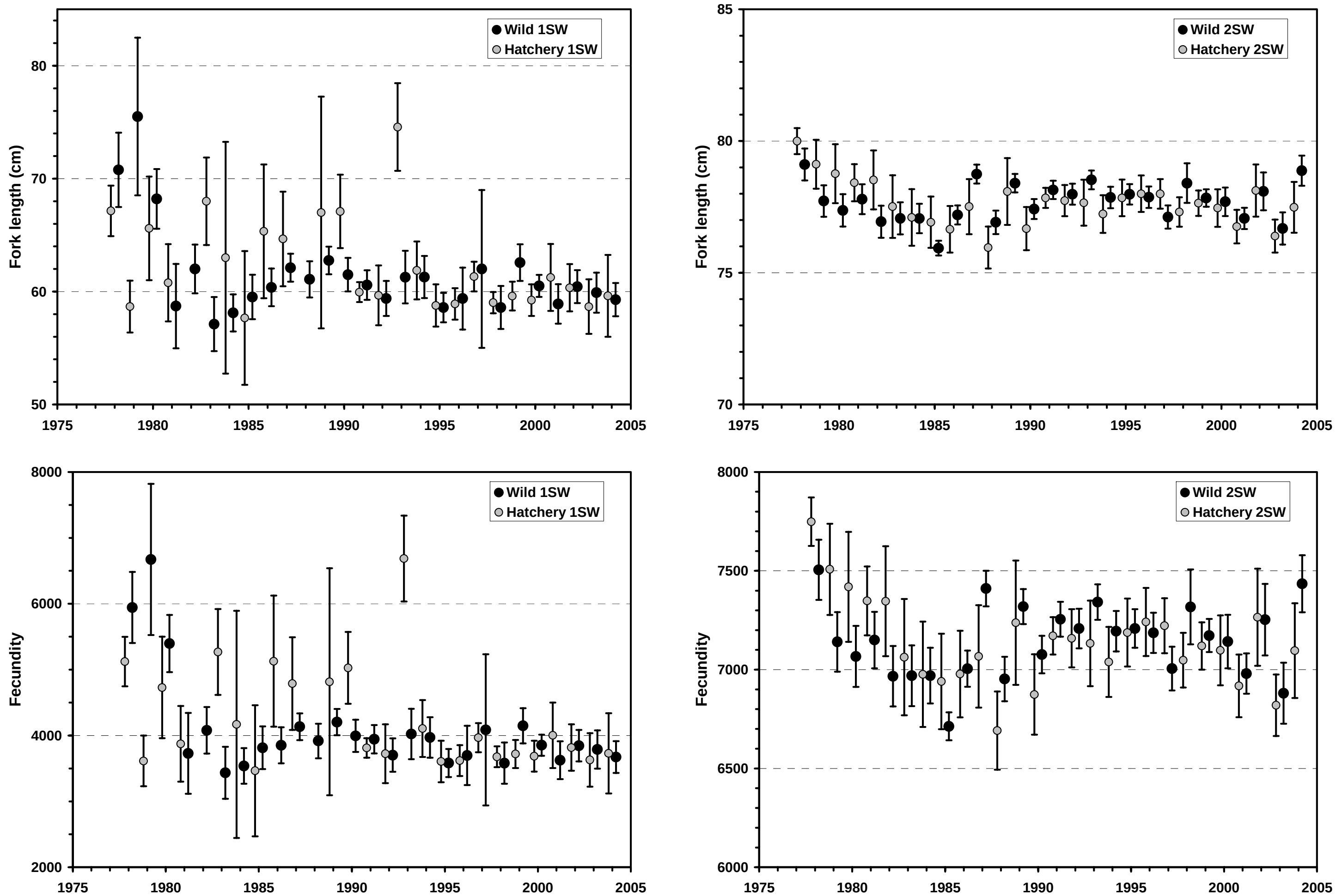


Figure 13. Changes in mean fork length (upper panels) and fecundity (lower panels) of female 1SW (left) and 2SW (right) maiden salmon of wild and hatchery origin from the Saint John River. Mean +/- 2 standard error bars are shown.

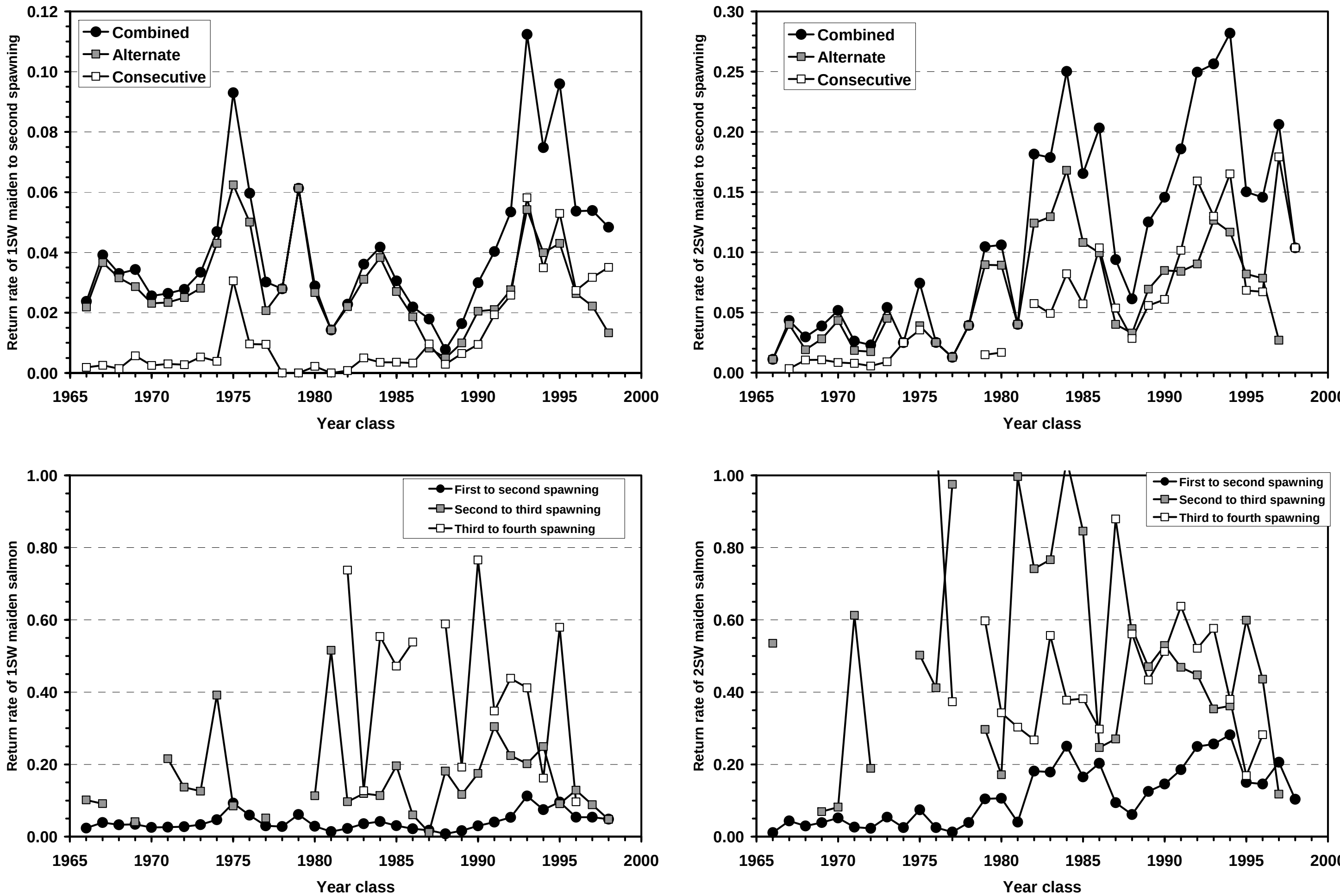


Figure 14. Return rates of wild 1SW maiden salmon (left panels) and wild 2SW maiden salmon (right panels) to a second spawning as alternates and consecutives (upper panels) and to multiple spawning events (lower panels) by year class for the Miramichi River.

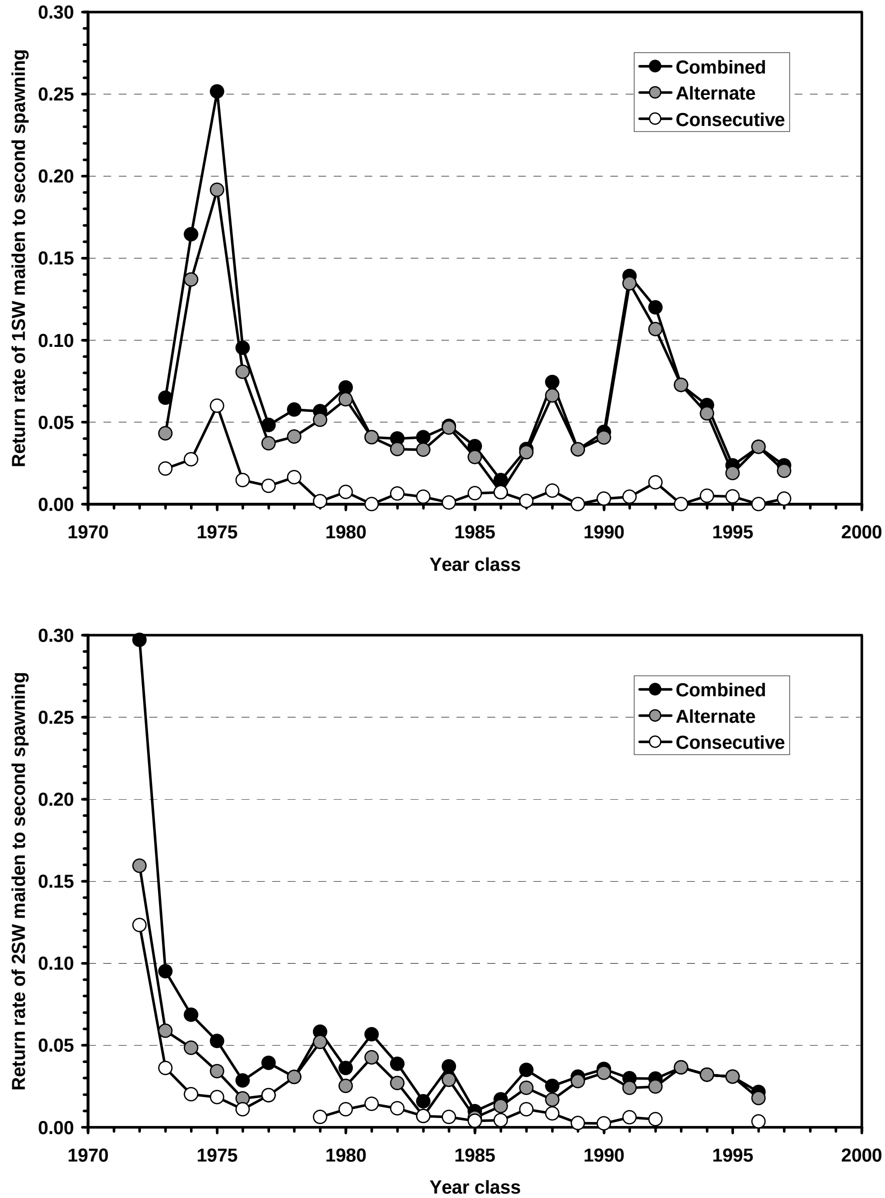
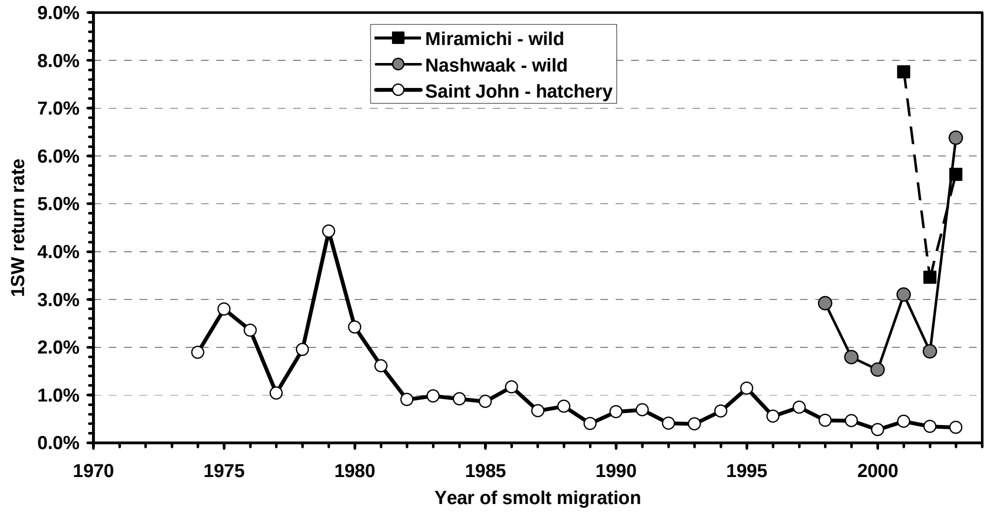


Figure 15. Return rate of wild 1SW (upper) and 2SW (lower) maiden salmon to a second spawning in the Saint John River, by year class.



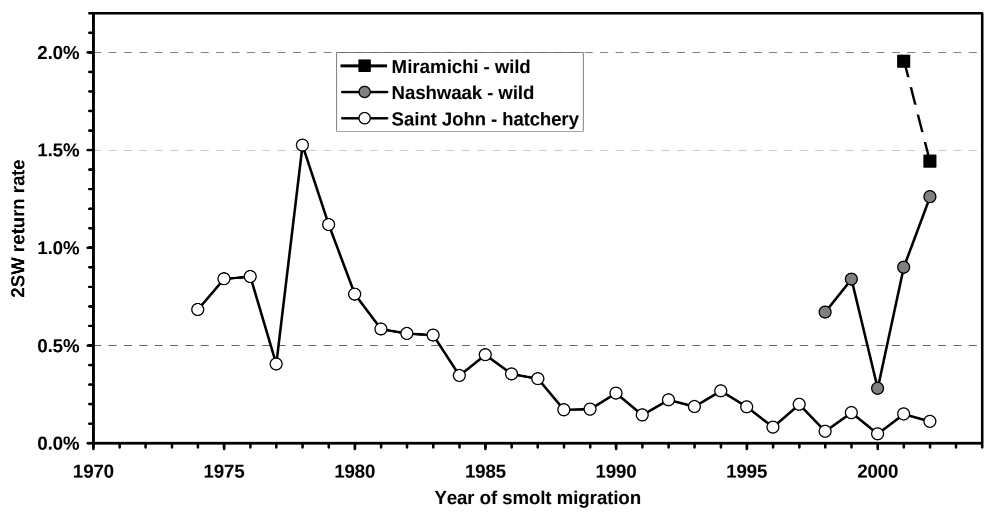


Figure 16. Return rates of hatchery origin smolts from the Saint John River and wild smolts from the Nashwaak and Miramichi rivers to 1SW (upper) and 2SW (lower) maiden salmon.

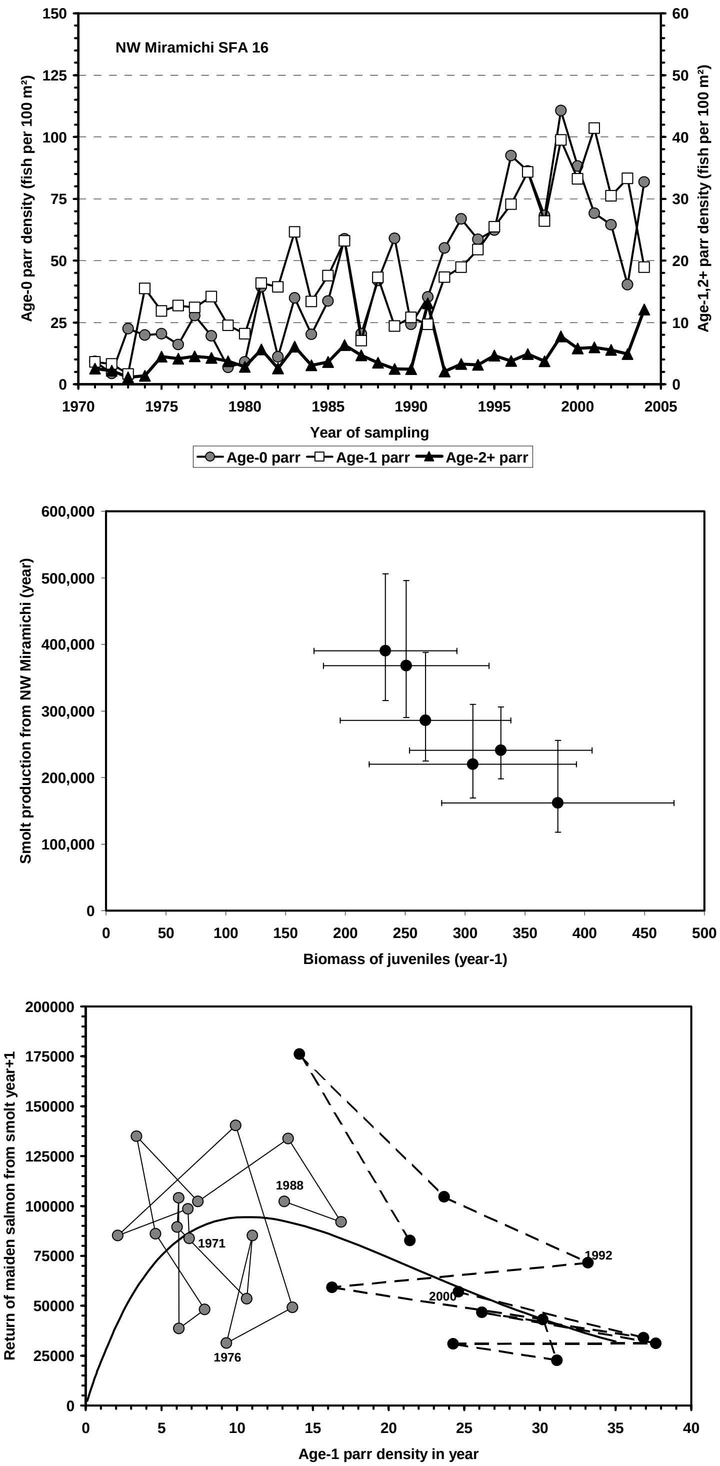


Figure 17. Miramichi juvenile abundance (upper panel), smolt production relative to juvenile biomass of the Northwest Miramichi (middle panel) and the association between age-1 parr density in the year prior to the smolt emigration and the returns of maiden fish from the corresponding smolt group. Black symbols in the lower panel correspond to the years in the lower productivity phase as described by Chaput et al. (2005). The curve in the lower panel is the mean stock and recruitment curve assuming over-compensation.