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Hydrological Conditions for Atlantic Salmon Rivers in the Maritime Provinces in 1997

by

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ABSTRACT

This paper provides recent (1997) and historical information on hydrological conditions for selected Atlantic salmon (*Salmo salar*) rivers within the Maritime Region of DFO. High and low flow for each river were calculated based on historical annual high and low flow series. Stream water temperatures were reported in 10 river systems.

Discharges were above normal in January with NB rivers experiencing excessive monthly flow conditions. March and April showed below normal flows for rivers in NB and part of NS. Such below normal conditions in March and April resulted in a one month delay for high flows. In fact, excessive flows were observed May for most of the region. The spring breakup of 1997, although later than normal, was generally characterized as average with most rivers having floods between a 2-year and 5-year flood event. NS rivers showed less severe spring floods with flows lower than a 2-year event. A few rivers showed higher spring peaks such as the Saint John River which reached a 10-year flood and Wilmot River at above the 5-year event.

Low flow conditions in 1997 were similar throughout the area with low discharges from July to the end of October. Deficient flows persisted to the end of 1997 for some rivers with record lows in December (Nashwaak, SW Miramichi and Wilmot Rivers). On a daily basis, low flows of 1997 were between a 2-year and 5-year event with only LaHave River showing lower flows than the 5-year event.

River water temperatures in 1997 were characterized by minor high temperature events between late June and mid-August. Tobique Fishway reached its peak water temperature on July 3 at 24.1 °C, Mactaquac Fishway on July 21 at 22.9 °C, Nashwaak River on July 27 at 26.6 °C and Kennebecasis River on August 11 at 20.6 °C.

In the Miramichi River basin, most rivers reached their peak water temperature around mid-August (10-11); Catamaran Brook (17.6 °C), Little Southwest Miramichi River (24.9 °C), Northwest Miramichi River below Big Hole (26.2°C); Southwest Miramichi River at Sister’s Brook (23.4 °C) and Northwest Miramichi River at the Barrier Fence (19.8 °C). Dungarvon River reached its peak temperature on July 27 at 23.4 °C while Northwest Miramichi River at Eel Ground recorded its peak on July 7 at 26.8 °C.

The study of a flow variability score on the Southwest Miramichi River to quantify abnormal events showed that over the past 8 years it varied between 6 and 13 with high values in recent years. Flow variability was signficantly related to adult salmon returns.

RÉSUMÉ

Le présent article a pour objet de fournir de l'information sur les conditions hydrologiques qui ont prévalu dans quelques rivières à saumon de l'Atlantique (*Salmo salar*) dans les provinces Maritimes en 1997. Les conditions hydrologiques à long terme sont également fournies. Les caractéristiques de débits de crue et d'étiage ont été calculées pour chaque rivière en utilisant des données historiques de débits maximum et minimum annuels. La température de l'eau a été obtenue pour quelques rivières, et les caractéristiques de température, tel que les événements de température élevées, ont été présentées.

En général, le débit des rivières était supérieur à la normal pendant l'hiver 1997 surtout en janvier au Nouveau-Brunswick. Les débits en mars et avril étaient plus faibles que la normale au Nouveau-Brunswick et en Nouvelle-Écosse. Ces conditions de débits faibles en mars et avril, résultèrent en des débits élevés en mai, alors un délai les crues printanières en mai. Même que les débits de crue étaient plus tard cette année, leurs récurrences étaient faibles et d'environ 2 à 5 années. Les rivières en Nouvelle-Écosse démontrèrent des débits plus faible qu'une récurrence de 2 années. Quelques rivières démontrèrent des débits plus élevés tel que la rivière Saint Jean (10 années) et la rivière Wilmot (supérieur à 5 années).

Les conditions de débits faibles en 1997 étaient similaires sur toute la région avec une période de débit faible de la mi-août jusqu'à la fin octobre. Des débits faibles extrêmes furent mesurés aux rivières suivantes en décembre: Nashwaak, SW Miramichi, et Wilmot. Sur une base journalière, les débits faibles étaient d'une récurrence de 2 à 5 années avec la rivière LaHave démontrant des conditions d'étiage plus sévère.

Les variations dans la température de l'eau en 1997 peuvent être caractérisées par quelques événements importantes de la fin juin jusqu'à la mi-août. La rivière Tobique (passe à poisson) atteint son maximum le 3 juillet à 24.1 °C, Mactaquac le 21 juillet à 22.9 °C, la rivière Nashwaak le 27 juillet à 26.6 °C et la rivière Kennebecasis le 11 août à 20.6 °C.

La plupart des cours d'eau du bassin de la rivière Miramichi ont observées leur température maximum à la mi-août ; ruisseau Catamaran (17.6 °C); rivière Little Southwest Miramichi (24.9 °C); rivière Northwest Miramichi à Big Hole (26.2 °C); rivière Northwest Miramichi à la barrière (19.8 °C). La rivière Dungarvon atteint son maximum de température le 27 juillet à 23.4 °C, tandis que la température de l'eau maximum de la rivière Northwest Miramichi à Eel Ground a été observée le 11 août à 20.6 °C.

Une étude du débit de la rivière Southwest Miramichi a été effectuée en quantifiant les événements extrêmes (supérieur ou inférieur à la normale) par un indice de variabilité du débit. Cette indice, représentant les conditions en eau douce pour les saumon juvéniles, augmenta durant les dernières 8 années de 6 à 13 et démontra uns relation avec les retours de saumons adultes.

INTRODUCTION

Hydrological events are important in the management of fisheries and aquatic resources. Some of these events such as streamflow variability can affect stream biota at different life stages and also during different seasons of the year. Salmonids can be affected by stream discharge such as high flows (Elwood and Waters 1969; Erman *et al.* 1988). Similarly, low flows can affect fish movement and stream water temperature (Cunjak *et al.* 1993; Edwards *et al.* 1979). River water temperatures can play an important role in the distribution of fishes as well as influence parameters such as dissolved oxygen. In order to increase our understanding of streamflow variability and extreme events in particular Atlantic salmon rivers for the purpose of assessing Atlantic salmon stocks, we need to study the stream hydrology for these rivers and in particular the streamflow conditions. As a result of the recent decline in returning Atlantic salmon to some Maritime rivers and in particular to the Miramichi River (Chaput et al. 1998), the freshwater conditions that resulted in abnormally high and low water events were studied using a streamflow variability index. Data on the Southwest Miramichi River were used and the analysis was carried out using monthly flow data.

The objective of the present study is to analyse regional hydrological data for important Atlantic salmon rivers within the Maritimes Region for use in aquatic resource management. The specific objectives are: a) to provide an overview of the monthly precipitation and flow conditions for 8 rivers, b) to determine the high and low flow months in 1997, c) to determine the frequency of floods and low flows events in 1997, d) to analyze data on high water temperature events for some Atlantic salmon rivers in the studied region, and e) to identify abnormal streamflow events over the past 8 years in the Southwest Miramichi River.

METHODS

The regional hydrological analysis was carried out using historical hydrometric data from gauged stream and rivers in the study region. Historical data and 1997 data were obtained from Environment Canada. These data were used to calculate high and low flow characteristics for different recurrence intervals (T-year events). Annual flood flows and low flows were fitted to a statistical distribution function in a frequency analysis to estimate the T-year events (Kite 1978). For instance, the 25-year (T = 25) low flow is a low flow which occurs on the average every 25 years such that 4 lowflow events occurr in 100 years on average. Flood frequency analysis was based on a three-parameter lognormal distribution function and on historical annual flood observations (Kite 1978). In contrast, the type III extremal distribution was used to estimate the low flow frequency events using daily minimum discharge on an annual basis (Kite 1978).

Historical and 1997 data on precipitation were obtained from Environment Canada for 7 sites in the Maritime Provinces. Monthly precipitations were compared to long-term values. Monthly flow characteristics in 1997 were also compared to long-term average flow conditions. The high and low flow months were estimated for each river system. In the present study, a flow above the 75% percentile identifies an excessive monthly flow condition while a flow below the 25% percentile denotes a deficient flow (Environment Canada 1995).

Data on water temperature were analyzed for 11 sites across the Maritime Provinces. Maximum daily mean water temperatures were presented as well as the daily variations, measured by the difference between the daily maximum and daily mean. The mean daily variation (mean difference) and the maximum daily variation (maximum difference) were calculated during the warm period of the summer i.e. late June (day 140) to late August (day 240). The number of days with maximum water temperatures exceeding 23 °C was also calculated as an indicator of stress for salmonids.

Abnormal events were defined using a flow variability score. Any monthly discharges within the 25th and 75th percentiles were attributed a score of zero, meaning that these flows were considered normal. Monthly flows exceeding the 75th percentile and lower than the 90th percentile were attributed a score of 1. Such flows represent higher than normal discharges. Similarly, monthly discharges between the 25th and 10th percentiles were labelled as lower than normal flow with a score of 1. Monthly discharges exceeding the 90th percentile were attributed a score of 2, and were identified as much higher than normal. Monthly flows below the 10th percentile were identified as much lower than normal and were also attributed a score of 2.

STUDY RIVERS

The study region comprises 8 Atlantic salmon rivers within the Maritime Provinces for hydrological studies and 11 water temperature sites (Figure 1). These rivers are: Nashwaak River (01AL002, NB), Saint John River (01AK010, NB), Restigouche River (01BJ007, NB), Southwest Miramichi River (01BO001, NB), Wilmot River (01CD003, PEI), Northeast Margaree River (01FB001, NS), St. Marys River (01EO001, NS), and LaHave River (01EF001, NS).

The drainage basin of the studied rivers ranged from 45.4 km^2 (Wilmot River) to 39900 km^2 (Saint John River; Table 1). LaHave and St. Marys Rivers have the longest daily discharge time series with over 80 years of record. The mean annual flow (MAF), which is a function of drainage area, varies between 0.922 m^3/s for Wilmot River to 810 m^3/s for Saint John River. To compare discharge between basins of different sizes, the mean annual runoff was used. This represents the mean annual flow (MAF) expressed in unit discharge in mm (discharge per drainage area). The region has a wide range of runoff characteristics depending on parameters such as the amount of rainfall, soil type, etc. Northern New Brunswick and Prince Edward Island showed the lowest runoff with only 640 mm (Saint John River, NB and Wilmot, PEI) and 665 mm (Restigouche River, NB) compared to more than double this value at 1485 in Cape Breton (Northeast Margaree River, NS). The precipitation varies from 1010 mm to 1600 mm (Table 1). The coefficient of variation (CV) of monthly flow characteristics show more stable flow regimes for some rivers than for other rivers. For instance, Wilmot River has a more stable flow regime with a CV of 0.49 compared to Restigouche River with a CV of 1.11 (Table 1).

RESULTS

PRECIPITATION IN 1997

Long-term precipitation data (1953-1990) are presented in Table 2 for comparative purposes. The highest monthly precipitation in 1997 was recorded in Kejimkujik in March with a total value of 186.0 mm. In contrast, the lowest precipitation recorded in the region was at Halifax with a precipitation in July of only 11.7 mm. Most area showed average precipitation in the winter of 1997 except NS which showed above average values in January and March (Table 2) The Maritime provinces showed below average precipitation in July and August with some values below 35 mm except in Chatham and Margaree Forks. In the Miramichi area the low precipitation month was in October at 36.1 mm rather than during the summer.

HYDROLOGICAL CONDITIONS IN 1997

In general, winter flows (January to March of 1997) were both excessive and deficient (Table 3). January flows were excessive in Nashwaak, Restigouche and Southwest Miramichi rivers (Table 3). The greatest deviation from the long-term monthly flow was observed in Nashwaak River (+93%, Figure 2a) with a discharge of 35.2 m^3/s compared to an average of 18.2 m^3/s for January. The Southwest Miramichi River experienced excessive flows of 88.9 m^3/s (Table 3) which represents +57% of the monthly value (Figure 2a). For rivers in PEI and NS, only Wilmot and Northeast Margaree River experienced excessive flows in the winter of 1997.

During March and April, most rivers were below normal discharge (Figure 2 and Table 3). The most deficient flows was recorded in St. Marys River in February at -67% (Figure 2b). The February monthly discharge was 13.1 m^3/s compared to the monthly average of 40.3 m^3/s. Below normal flows in the order of -50% occurred in other rivers in the Maritime Provinces, especially in NB (Figure 2).

The spring high flow of 1997 was delayed with deficient flows in April, resulting in excessive flows in May. In fact, most rivers in May were excessive with Nashwaak River being the most affected at +76% of the average monthly flow condition (Figure 2a). Excessive flows in NS were in the range of +37% to +67%.

The summer flows of 1997 can be characterized as normal in June and July. By July, low water conditions appeared in NS with a deficient flow in the St. Marys River. Most Maritimes rivers showed below normal values from August to November (Figure 2) with deficient flows persisting for 4 months on Saint John, Southwest Miramichi, Wilmot and LaHave Rivers. In autumn 1997, LaHave River was the most affected river by low water conditions with flows of -94% in October (Figure 2b). The monthly discharge was 1.1 m^3/s compared to the average of 19.8 m^3/s (Table 3). October was also a low flow month in NB with all rivers in the range of -73% to -79% of average monthly values (Figure 2a).

Low water conditions persisted through December with deficient flows in Nashwaak, Wilmot and Southwest Miramichi Rivers. In December, these rivers experienced new record low monthly flows. The new record low flow at Nashwaak was at 5.74 m^3/s compared to the average of 33.3 m^3/s, and in Southwest Miramichi the low flow was 21.7 m^3/s compared to a long-term mean of 98.8 m^3/s. The new low flow at Wilmot River was 0.289 m^3/s compared to a long-term mean of 0.884 m^3/s for December.

In 1996, higher annual discharges were recorded than in previous years especially in NB (Figure 3a). This was largely due to excessive flow throughout the winter of 1996 (January to March) and in July 1996 (Caissie, 1997). In 1997, average to below average annual conditions were observed throughout the Maritime Provinces. For instance, NB rivers were between -5% (Restigouche River) and -19% Nashwaak River) below long-term mean values. NS rivers experienced from -18% LaHave River) and -22% (St. Marys River) of the long-term mean except for Northeast Margaree which was only at -7% (Figure 3b). The mean annual flow for Wilmot in 1997 represented -13% of long-term conditions. Other years of interest were 1979 and 1990 when high water years throughout the Maritime provinces were observed. It was also observed that in NS, the annual flow variability was smaller over the past few years while in NB it remained relatively high Figure 3).

Daily discharge were more variable in NS in 1997 than in NB (Figure 4 and 5). Winter flows in NB were somewhat more stable compared to those of NS. In NS, a mid-winter thaw period occurred in late January and resulted in peak flows in both St. Marys (253 m^3/s, Jan 27: day 27) and Northeast Margaree (110 m^3/s, Jan 26; day 26) rivers (Figure 5c and 5d). LaHave showed much higher flows in winter 1997 than other rivers in the region (Figure 5b). Summer and autumn flows were low for most rivers in the region this year and remained low until the end of the year except for the St. Marys and Northeast Margaree Rivers, where flows were higher by November and December respectively.

The maximum daily discharges in NB rivers were reached early to late May this year with two distinct peaks on May 2-3 (day 122 – 123) and May 17-18 (day 137-138), depending on the river (Figure 4). Peak flow from the Nashwaak River was observed on May 2 at 353 m^3/s (Figure 4a). This flow represents a discharge in the range of a 2-year flood (Table 4). Saint John River experienced its high flow on May 18 (Figure 4b, day 138) with a maximum daily discharge of 8940 m^3/s, an event in the range of a 10-year flood. Restigouche River reached a discharge of 1600 m^3/s on May 18 which is a 2-year flood event. Similar to Nashwaak River, the Southwest Miramichi River peaked early May at 961 m^3/s which also represents a flow within a 2-year event.

In PEI, the maximum daily discharge was realized March 30 (day 89) on Wilmot River (Figure 5a). The peak discharge was measured at 16.6 m^3/s and represents a 5-year flood event (Table 4). The winter flow values in Wilmot River could change slightly in winter as the current data are not corrected for ice conditions (preliminary data from Environment Canada). In Nova Scotia, LaHave River showed a maximum daily flow on May 5 (day 125) at 104 m^3/s (Figure 5b; day 125). Such a flow condition represents an event below a 2-year flood. Marked variability in flow conditions were observed on LaHave River during the winter of 1997. A peak flow of 325 m^3/s was measured on St. Marys River on May 5 (day 125), which represents less than a 2-year flood event. For Northeast Margaree River, the peak flow was also observed on May 5, with a discharge of 133 m^3/s (less than 2-year flood).

Low flow conditions in 1997 were of a longer duration this year, from July to end of December for some rivers. In New Brunswick, the low flow period in 1997 was predominantly in late October (Figure 4). The minimum daily discharge on the Nashwaak River was observed on October 26 (day 299) at 3.69 m^3/s, a flow lower than a 2-year event (Table 5). For the Saint John River, as in previous years, the regulated flow the dam makes it difficult to assess the natural low flow conditions. Nonetheless, the lowest daily discharge was observed on October 18 (day 291) at 60.9 m^3/s, which is a 2-year event. As for the Restigouche River, the low flow in 1997 was observed on October 26 (day 299) with a discharge of 25.9 m^3/s. This flow represents a higher discharge than a 2-year low flow. In Southwest Miramichi River, the low flow was also observed on October 26 at 17.4 m^3/s, which was between the 2-year and 5-year low flow event.

Wilmot River showed low flow conditions extending from July to the end of December in 1997 (Figure 5a). The daily minimum discharge was recorded on Dec. 29 (day 363) at 0.232 m^3/s which represents a low flow within the 2 to 5 year recurrence interval. In Nova Scotia, LaHave River showed the most severe low flow conditions in the studied area with a minimum daily discharge of 0.572 m^3/s October 24 (day 297), a 5-year low flow event (Table 5). Similar to LaHave, the St. Marys River reached low flow conditions from July to late October with a discharge of 2.29 m^3/s on October 25 (day 298), however the minimum daily discharge in 1997 was measured on August 22 (day 234) at 1.10 m^3/s. This low flow is in the vicinity of a 4-year low flow event (Table 5). The low flow period on the Northeast Margaree River was observed on August 29 (day 241) with a discharge of 3.36 m^3/s. This flow was higher than the 2-year low flow event. Low flow conditions persisted until the end of September with flows of only 3.42 m^3/s on September 20 (Figure 5d; day 263).

In general, peak flows in 1997 were close to a 2-year flood event in New Brunswick except Saint John River which reached a 10 year event. In PEI, close to a 5-year event was observed. Most of Nova Scotia rivers were not severely affected by high flows in 1997 with discharge lower than the 2-year event. As for low water conditions in 1997, most rivers in the Maritime Provinces showed similar results with low discharge of between a 2 and 5-year low flow event, except LaHave River which showed lower discharge (i.e. higher return event). Restigouche and Northeast Margaree Rivers showed low flows higher than the 2-year low flow event which means that these rivers were not highly affected by low water conditions.

STREAM WATER TEMPERATURES

River water temperatures were available for 11 sites within the Maritimes Region in 1997. Compared to previous years, the conditions this year can be characterized by fewer and less severe high water temperature events than previous years (e.g. 1994, 1995, see Caissie 1995; Caissie 1996). During the summer of 1997, the most significant high water temperature events occurred between June 29 (day 180) and August 29 (day 241).

Stream water temperature variations for Nashwaak River and Mactaquac Fishway are shown in Figure 6a (see Figure 1 for site location). Nashwaak River temperatures showed many peaks between June 29 (day 180) and August 13 (day 225) with the highest peak on July 2 (day 183). Two other high peaks occurred on July 27 (day 208) and August 11 (day 223; Figure 6a). During the early July event, Nashwaak River reached a daily mean temperature of 24.5 °C. The other events were 23.6 °C (day 208) and 23.2 °C (day 223) respectively. The maximum recorded temperature in Nashwaak River for 1997 was on July 27 at 26.6 °C (Table 6). As for Mactaquac Fishway, the maximum daily river temperature occurred on July 21 (day 202) at 22.5 °C. It can be observed that the Mactaquac Fishway temperatures are less variable, and the mean daily water temperature remained over 20°C for most of the summer period (from day 180 to 250). The maximum recorded temperature for Mactaquac Fishway in 1997 was on July 21 at 22.9 °C (Table 6).

Kennebecasis River reached its maximum mean daily water temperature on August 12 (day 224) at 18.6 °C (Figure 6b), with its maximum recorded temperature in 1997 at 20.6 °C the day before, on August 11 (Table 6). Maximum mean daily water temperature at the Tobique River Fishway was measured at 23.6 °C on July 03 (day 184), and the maximum recorded temperature was on the same day at 24.1 °C.

Kennebecasis River water temperatures, with no daily mean temperature above 20 °C, were lower than Nashwaak River, Mactaquac Fishway and Tobique River Fishway temperatures.

River water temperatures were available at 7 sites within the Miramichi River basin in 1997 (Figure 7; see Figure 1 for site locations). Water temperatures on the Northwest Miramichi River at the Barrier Fence, were generally lower during most of the summer season Figure 7a). Other rivers such as Dungarvon River experienced intermediate temperatures while the mean daily temperatures at Eel

Ground were higher and less variable than the others for part of the summer (Figure 7a). Water temperatures on the Northwest Miramichi River below Big Hole Pool were similar to those of Little Southwest Miramichi River and Southwest Miramichi River at Sister's Brook (Figure 7b).

Water temperatures in the Miramichi River were similar to those from other Maritime Region rivers with high water temperature events observed from early July to mid-August. Little Southwest Miramichi River and Northwest Miramichi River below Big Hole experienced the highest daily mean temperature in July and August (Figure 7b). On July 28 (day 208), the mean daily temperature reached 22.2°C for Little Southwest Miramichi while on August 11 (day 223) a mean temperature of 23.1 °C was measured below Big Hole Pool (Figure 7b; Table 6). On July 27 (day 208), Dungarvon River reached a maximum of 20.1 °C (Figure 7a; Table 6). Southwest Miramichi River at Sister's Brook reached its maximum daily temperature on August 11 (day 223) at 21.6 °C while Northwest Miramichi at Eel Ground reached 21.9 °C the next day. The lowest daily peak temperatures during 1997 in the Miramichi River basin were monitored in the Northwest Miramichi River at the Barrier Fence with a value of 16.1 °C (July 27; day 208) and at Catamaran Brook at 15.9 °C (August 11; day 223).

Maximum recorded temperature in Little Southwest Miramichi River and in the Northwest Miramichi River below Big Hole Pool were at 24.9 °C and 26.2 °C respectively on August 10 (day 222) for both rivers (Table 6). Most other Miramichi tributaries showed lower maximum values except Northwest Miramichi River at Eel Ground which recorded a high value of 26.8 °C, the highest in the Miramichi for 1997. Dungarvon River and the Northwest Miramichi River at the Barrier Fence reached an annual peak values of 23.4 °C and 19.8 °C respectively. These high water temperatures were recorded on August 10-11 (day 222-223).

The difference between the daily maximum and daily mean was calculated during the warm period of the summer i.e. late June (day 140) to late August (day 240). The mean difference as well as the maximum difference are presented in Table 6. Mataquac Fishway temperatures showed less daily variations at 0.34 °C than did Little Southwest Miramichi River with a mean difference of 2.7 °C. The maximum departure from the mean daily temperature for Little Southwest Miramichi River was 4.2 °C. The maximum observed difference for Northwest Miramichi River at Eel Ground was 6.4 °C (Table 6).

The last column in Table 6 presents the number of days on which the daily maximum temperature exceeded 23 °C. River water temperatures never exceeded 23 °C during the summer of 1997 at the Mataquac Fishway, Kennebecasis River, Catamaran Brook, or at Northwest Miramichi River at the Barrier Fence. Other rivers such as Dungarvon River, Southwest Miramichi River at Sister's Brook and Tobique River Fishway showed fewer than 5 days in 1997 (Table 6), where Northwest Miramichi River at Eel Ground showed 6 days with maximum temperatures above 23 °C. Northwest Miramichi River below Big Hole and Little Southwest Miramichi River showed similar results, having 12 and 14 days respectively with maximum water temperatures exceeding 23 °C. The highest water temperature recorded in 1997 occurred in the Nashwaak River where there were 24 days having maximum water temperatures above 23 °C (Table 6).

Water temperatures for 1997 were compared to 1991-96 data at Catamaran Brook. The highest monthly mean water temperature was recorded in July at 13.9 °C (Table 7). The May temperature was the lowest of the time series recorded at only 3.8 °C. These lower water temperatures in May delayed movements of smolts and the emergence of fry (pers. com.,P. Hardie, DFO and R.A. Cunjak, UNB). Figure 8 shows the general variation in temperatures over the past 4 years at Catamaran Brook. Data show that the water temperatures were lower than normal in May (after day 121). Below normal temperatures were also observed during the warmer period of the summer i.e. during the peak of the Fourier series. The autumn temperatures were characterized as normal in 1997 with the exception of a cold spell on October 27 (day 300) for which the water temperatures dropped to close to 0 °C.

POTENTIAL IMPACTS OF STREAMFLOW VARIABILITY

Using the flow variability score to identify atypical monthly flow conditions, the Southwest Miramichi River showed many events over the past 8 years (Figure 9). One *H* represents a monthly discharge with a score of one as identified above (75th<Q<90th percentile) while two *H*s represent a score of two (Q>90th percentile) or a much higher monthly flow. Similarly, one *L* represents a score of one or a lower than normal monthly flow (10th<Q<25th percentile) and two *L*s (Q<10th percentile) a score of two. The use of solid dots in Figure 9 represents the lowest or highest monthly discharge over the past 28 years (1970-1997).

For instance, a flow variability score of 7 was calculated in 1990 with all monthly flows events higher than normal (Febuary, April, August, October to December, Figure 9). Among these higher than normal monthly flows, August was identified as much higher with a score of two. In 1991, the flow variability score was similar to 1990 at 7 while 1992 showed a value of 6.

In general, it was observed that over the past 8 years the Miramichi River experienced many events identified as lower or higher than normal. The flow variability score ranged from 6 to 13 and the most significant years were 1993, 1994 and 1997.

The flow variability score in 1993 was calculated at 9 which was an increase over the previous 2 years. In addition to a higher score in 1993, the winter showed extremely low winter flows. In fact, March had the lowest monthly discharge since 1970. June and December were much higher than average (Figure 9). In 1994, a high flow variability score of 13 was observed starting with a higher monthly flow in April. The spring breakup of 1994 was not only the result of high water conditions, but also severe ice jams were observed in the Miramichi River. Most of the flow variability score realized in 1994 was due to the low flows in summer and autumn. In 1995, the flow variability score was less than in 1994 and was calculated at 8. The difference in 1995 compared to previous years was the low flow conditions in autumn. Compared to 1994, three consecutive months showed record low monthly flows (Jul., Aug. and Sep.), and a record high flow in November.

A flow variability score of 7 was observed in 1996, with higher monthly flows in winter. These higher than normal flows in winter of 1996 resulted in breakups during January in some Miramichi rivers. Such mid-winter breakups are unusual for January and could potentially impact on aquatic resources. In 1997, the flow variability score increased to 12 as a result of a mix of higher and lower than normal flows. In winter, only February was normal with the timing of the spring high flows delayed in May (April=Low and May=High). Similar to 1994, 1997 showed prolonged low water conditions during five months from August to December with a record low monthly flow in December.

The flow variability score was added over the period of 4 years to reflect the life stage of salmon in freshwater (from egg deposition to smolt migration). The summation of flow variability increased over the year (1994 to 1997; Figure 10).

If we were to hypothesize that fish populations are affected by abnormal freshwater events, some years would be expected to show greater impact on juvenile Atlantic salmon than others. Among the events that contributed to increasing the flow variability score during these years, some were more important than others. The winter low flow of 1993 is one event as were the low summer flows of 1994, 1995 and 1997. The spring breakup of 1994 and the January breakup of 1996 were important events for the Miramichi River as they were associated with major ice jams. In particular, the January peak daily discharge in 1996 was estimated to be in the range of a 100-year event for that month.

The Atlantic salmon returns to the Miramichi River (Chaput et al. 1998) showed a significant relation with the freshwater life stage flow variability score (Figure 11). For small salmon, a significant linear regression was calculated at p=0.03, with r^2=0.0.52, while for large salmon the regression was significant at p=0.02 with r^2=0.54. Data suggests that a high flow variability score could potentially result in low returns of both large salmon and small salmon (Figure 11a and 11b).

SUMMARY

In summary, the streamflow conditions during 1997 were characterized by an above normal discharge during winter, especially in NB. The most affected river was Nashwaak with a flow +93% of average in January.

The spring runoff in 1997 was characterized as normal with peak flows close to a 2-year flood with the exception of Saint John River at a 10-year flood event. The most important characteristic of the spring peak in 1997 is that is was delayed as late as May 18 for some rivers. In fact, April showed deficient flows while May showed excessive flows this year.

Low flows were present in 1997 from July to the end of October and even to the end of December for some rivers. New record low monthly flows were monitored in December for Nashwaak, Southwest Miramichi and Wilmot rivers.

The higher than normal flows in May 1997 resulted in water temperatures below normal for that month. High temperature events in summer of 1997 were very similar to 1996 in magnitude and were not as severe as in previous years (i.e. 1994, 1995). Highest water temperature in Nashwaak River in 1997 was 26.6 °C compared to 24.2 °C in 1996. The maximum recorded temperature at Mataquac Fishway was 22.9 °C in 1997, compared to 22.6 °C in 1996 while Kennebecasis River showed 20.6 °C this year compared to 21.1 °C last year. Tobique River at the Fishway recorded 24.1 °C this year compared to 24.7 °C in 1996.

In the Miramichi River basin, the results were similar in 1997 to 1996. Highest water temperatures in Northwest Miramichi River at Big Hole Pool were 26.2 °C in 1997 compared to 26.8 °C in 1996. Little Southwest Miramichi River showed 24.9 °C (1997) compared to 26.1 °C (1996). Dungarvon River recorded a maximum of 23.4 °C this summer compared to 21.6 °C last year. Northwest Miramichi River at the Barrier Fence 19.8 °C (1997) and 19.3 °C (1996) and Northwest Miramichi at Eel Ground, 26.8 °C (1997) and 23.6 °C (1996).

Data from Catamaran Brook showed that in 1997, water temperatures were normal to below normal. Below normal temperatures were observed early in the season, during peak summer temperatures (late July) and for a brief period at the end of October. During other times of the year, water temperatures were very close to normal.

A flow variability score was used to quantify abnormal hydrological events. It was observed that over the past 8 years, this score varied between 6 to 13 on an annual basis with the highest values observed in 1994. The long-term flow variability score value expressed as the summation of the score during the freshwater life cycle of Atlantic salmon is increasing. Is was also observed that such flow variability score was significantly related to recent returns of small and large salmon.

ACKNOWLEDGMENTS
We thank the following people for the contribution in the present study: G. Chaput, R. Jones, D. Moore for the provision of data on river water temperatures; the Catamaran Brook field camp personnel for data collected during the past summer; and J.H. Conlon for his assistance in field hydrological data collection. Thanks are offered for the provision of data by Environment Canada (P. Noseworthy, Fredericton, NB; J. Spiers, Bedford, NS, and K. Freeman, Bedford, NS).

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Table 1. Hydrologic characteristics of eight Atlantic salmon rivers of the Maritime Provinces.

River	Area[1] (km^2)	N (years)	MAF (m^3/s)	Runoff (mm)	CV	Prec. (mm)
Nashwaak River (NB)	1450	35	35.0	761	0.80	1210
Saint John River (NB)	39900	32	810	640	0.88	1010
Restigouche River (NB)	7740	29	163	665	1.11	1080
Southwest Miramichi R. (NB)	5050	49	116	725	0.82	1090
Wilmot River (PEI)	45.4	26	0.922	640	0.49	1100
LaHave River (NS)	1250	81	34.4	870	0.59	1420
St. Marys River (NS)	1350	81	43.0	1007	0.54	1350
Northeast Margaree R. (NS)	368	80	17.4	1485	0.61	1600

[1] Area = Drainage area in km^2; N = Number of years of data; MAF = Mean Annual Flow in m^3/s; Runoff = Unit discharge (discharge per unit of area) in mm; CV = coefficient of variation of monthly flows; Prec. = precipitation in mm.

Table 2. Long-term mean (*LT;* 1953-1990) and monthly precipitation (mm) in 1997 for different areas in the Maritime Provinces.

Location		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Chatham A (NB)	*LT*	85.2	69.5	86.6	86.3	88.1	84.5	97.8	95.9	87.8	95.2	104.4	105.5	1087
	1997	105.8	87.0	105.8	53.2	128.2	149.6	65.8	81.8	83.2	36.1	57.1	80.5	1034
Fredericton A (NB)	*LT*	93.3	84.3	90.4	83.4	94.0	86.9	84.5	99.4	92.3	93.1	110.7	118.8	1131
	1997	73.2	59.8	97.0	42.1	111.8	83.3	74.2	34.7	77.5	-	-	-	-
Saint John A (NB)	*LT*	128.3	102.6	109.9	109.7	123.1	104.8	103.7	103.0	111.3	122.5	146.2	167.6	1433
	1997	113.6	105.9	116.2	55.2	105.6	61.2	61.2	14.8	105.3	-	-	-	-
Charlottetown A (PEI)	*LT*	106.3	91.5	92.2	91.8	96.8	91.1	81.6	88.6	94.1	111.7	121.9	133.2	1201
	1997	72.5	79.2	70.5	65.3	98.7	74.1	17.0	66.5	71.7	28.8	-	-	-
Kejimkujik (NS)	*LT*	141.3	113.0	117.6	108.8	101.5	96.7	104.2	87.9	97.1	116.4	145.0	167.5	1397
	1997	139.0	115.6	186.0	95.7	130.3	51.0	12.3	78.9	141.0	-	-	-	-
Maragaree Forks (NS)	*LT*	-	-	-	-	-	-	-	-	-	-	-	-	-
	1997	179.0	86.2	89.4	50.4	104.6	88.8	76.4	116.8	162.2	-	-	-	-
Halifax Int. A (NS)	*LT*	146.9	119.1	122.6	124.4	110.5	98.4	96.8	109.6	94.9	128.9	154.4	167.0	1474
	1997	156.1	76.9	131.5	80.4	145.7	86.4	11.7	46.1	91.1	-	-	-	-

Table 3. Long-term mean monthly flow (m^3/s) and 1997 average flow conditions for eight Atlantic salmon rivers in the Maritime Provinces (Data provided by Environment Canada 1990).

River		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Nashwaak River (NB)	LT	18.2	17.6	24.8	105	81.6	30.7	16.6	13.7	15.1	25.8	38.1	33.3
	1997	35.2E	16.0	10.3D	67.0D	144E	21.5	13.1	6.83	7.28	6.12D	12.3D	5.74DR
Saint John River (NB)	LT	376	376	508	2360	2320	763	431	408	386	604	657	566
	1997	413	282	272D	1720	3832E	720	343	152D	181D	127DR	371D	-
Restigouche River (NB)	LT	50.9	44.4	52.5	347	667	184	104	80.9	72.2	119	124	93.6
	1997	75.0E	41.1	30.4	165D	926E	174	101	50.6	40.1D	30.5D	69.5D	96.9
SW Miramichi R. (NB)	LT	56.7	49.8	66.4	316	318	112	60.0	54.7	54.1	89.5	116	98.8
	1997	88.9E	41.9	34.1D	203D	504E	106	74.9	28.5D	28.8D	23.8D	47.7D	21.7DR
Wilmot River (PEI)	LT	1.07	0.932	1.62	1.94	1.21	0.773	0.572	0.494	0.434	0.499	0.636	0.884
	1997	1.42E	0.699	1.45	2.26	1.03	0.715	0.513	0.389D	0.351D	0.306D	0.276DR	0.289DR
LaHave River (NS)	LT	47.0	38.4	53.3	73.3	38.9	20.6	11.3	8.97	8.89	19.8	42.7	50.7
	1997	39.7	43.7	39.9	69.6	65.0E	15.2	4.1	1.2D	1.4D	1.1D	11.9D	-
St. Marys River (NS)	LT	51.1	40.3	55.3	91.2	57.1	23.8	14.4	15.1	16.0	34.2	58.0	59.0
	1997	52.4	13.1D	27.7D	66.1D	84.2E	15.6	3.6D	3.2D	6.2	7.0D	71.4	-
NE Margaree River (NS)	LT	15.3	11.0	12.3	27.1	43.4	15.5	6.80	7.56	9.38	16.2	22.8	19.1
	1997	21.9E	10.2	7.9	13.5	59.6E	12.8	5.5	4.0	9.0	12.8	-	-

D= Deficient flow, <25%; E = Excessive flow, >75%; R = New record flow (see text for more details).

Table 4. Atlantic salmon rivers in the Maritime Provinces. Flood flows (m^3/s) at recurrence intervals (T) in years for eight rivers using a 3-parameter lognormal distribution function.

	Recurrence interval (T) in years					
River	2	5	10	20	50	100
Nashwaak River (NB)	321	478	580	676	799	890
Saint John Rvier (NB)	5910	7738	8854	9867	11124	12032
Restigouche River (NB)	1491	2118	2488	2819	3220	3505
SW Miramichi R. (NB)	834	1164	1391	1613	1909	2137
Wilmot River (PEI)	11.6	15.3	17.4	19.2	21.2	22.6
LaHave River (NS)	195	284	363	454	596	721
St. Marys River (NS)	382	509	593	675	782	863
Northeast Margaree R. (NS)	166	225	266	306	359	400

Table 5. Atlantic salmon rivers in the Maritime Provinces. Low flows (m^3/s) at recurrence intervals (T) in years for eight rivers using a Extremal type III distribution function.

River	Recurrence interval (T) in years					
	2	5	10	20	50	100
Nashwaak River (NB)	3.90	3.05	2.79	2.65	2.56	2.52
Saint John River (NB)	70.0	54.9	48.4	43.6	38.7	35.8
Restigouche River (NB)	22.6	16.8	14.1	12.3	10.6	9.65
Southwest Miramichi R. (NB)	19.8	15.1	12.9	11.2	9.70	8.84
Wilmot River (PEI)	0.295	0.223	0.189	0.164	0.139	0.125
LaHave River (NS)	1.59	0.619	0.355	0.226	0.147	0.119
St. Marys River (NS)	1.64	0.682	0.407	0.267	0.177	0.144
Northeast Margaree R. (NS)	3.02	2.35	2.01	1.73	1.44	1.26

Table 6. Stream water temperature characteristics of eleven Atlantic salmon rivers in the Maritime Provinces.

River	Maximum daily mean	Maximum recorded	Mean difference	Maximum difference	No of days above 23 °C
Nashwaak River (NB)	24.5 (Jul 2)	26.6 (Jul 27)	2.23	3.5	24
Mataquac Fishway (NB)	22.5 (Jul 21)	22.9 (Jul 21)	0.34	1.0	0
Kennebecasis River (NB)	18.6 (Aug 12)	20.6 (Aug 11)	2.16	3.4	0
Tobique R. at Fishway (NB)	23.6 (Jul 03)	24.1 (Jul 03)	0.63	2.1	3
Catamaran Brook (NB)	15.9 (Aug 11)	17.6 (Aug 10)	1.87	3.0	0
LSW Miramichi R. (NB)	22.2 (Jul 28)	24.9 (Aug 10)	2.71	4.2	14
NW Mira. at Big Hole (NB)	23.1 (Aug 11)	26.2 (Aug 10)	2.18	3.9	12
NW Mira. R. at Eel Grd (NB)	21.9 (Aug 12)	26.8 (Jul 07)	1.06	6.4	6
SW Mira. R. at Sister's Bk (NB)	21.6 (Aug 11)	24.2 (Aug 11)	2.39	4.0	3
Dungarvon River (NB)	20.1 (Jul 27)	23.4 (Jul 27)	2.34	3.9	1
NW Miramichi at Barrier (NB)	16.1 (Jul 27)	19.8 (Aug 10)	2.59	4.3	0

Table 7. Monthly water temperatures at Catamaran Brook Middle Reach (located in central New Brunswick, part of the Miramichi River Basin). All temperatures are expressed in °C.

Month	May	Jun	Jul	Aug	Sep	Oct
1991	7.76	12.45 *	14.66	15.07 *	n/a	n/a
1992	8.11 *	11.55	12.15	12.86	11.56	5.58
1993	5.80	10.52	13.39	14.79	10.69	4.49
1994	4.98	12.41	16.58	15.22	10.26	5.55
1995	5.89	13.52	16.24	15.26	9.88	7.18
1996	5.41	13.63	14.29	15.22	11.51	6.01
1997	3.84	11.48	13.91	13.72	11.04	4.79
Monthly Mean	5.61	12.19	14.46	14.51	10.82	5.60

Note : * indicates that these months had missing values, and therefore the average was calculated with a reduced sample and these months were not used in the calculation of the monthly mean. June 1991 (28 days), August 1991 (27 days), and May 1992 (19 days).

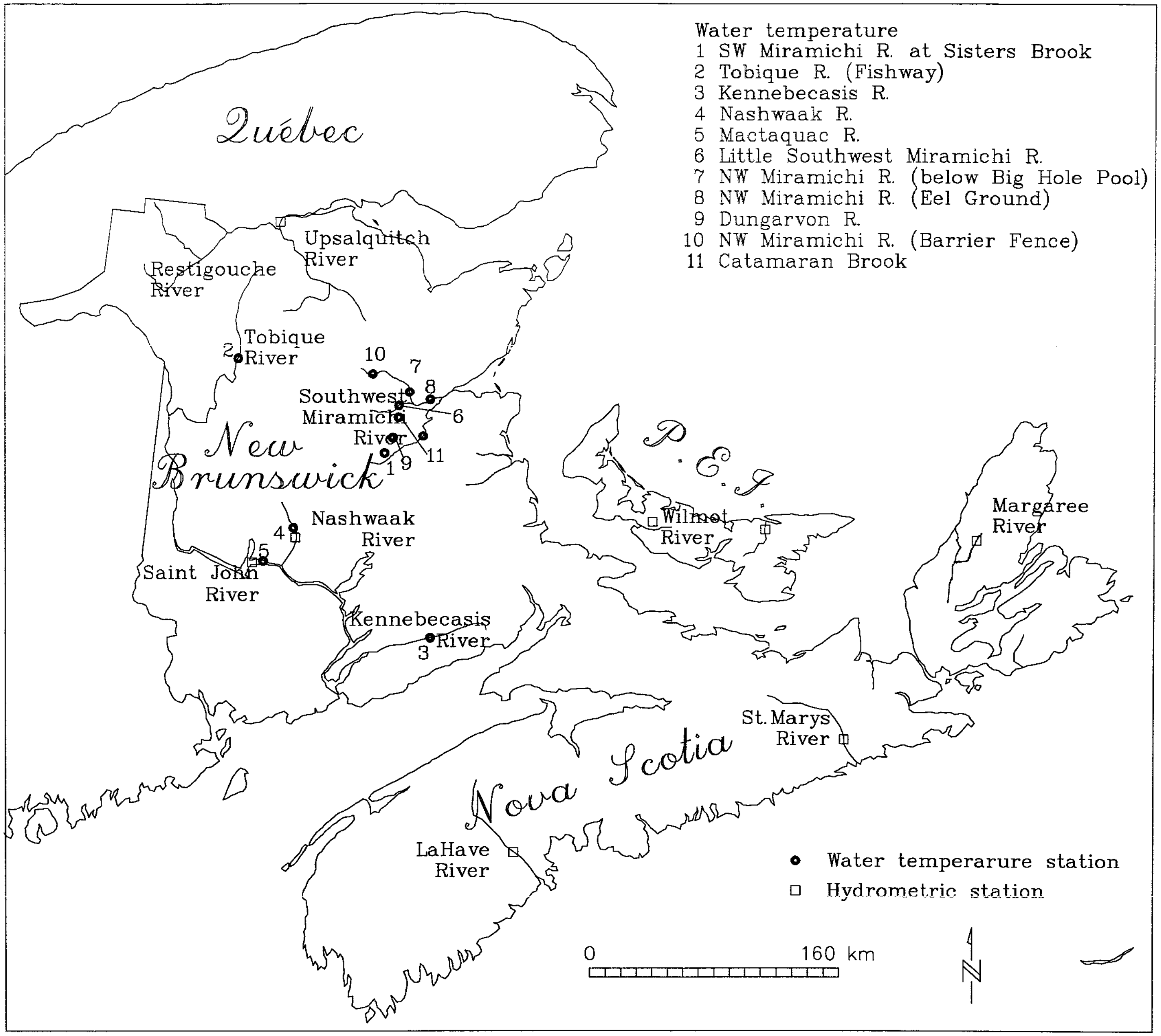


Figure 1. Location of hydrometric and water temperature stations on studied Atlantic salmon rivers in the Maritimes region of eastern Canada.

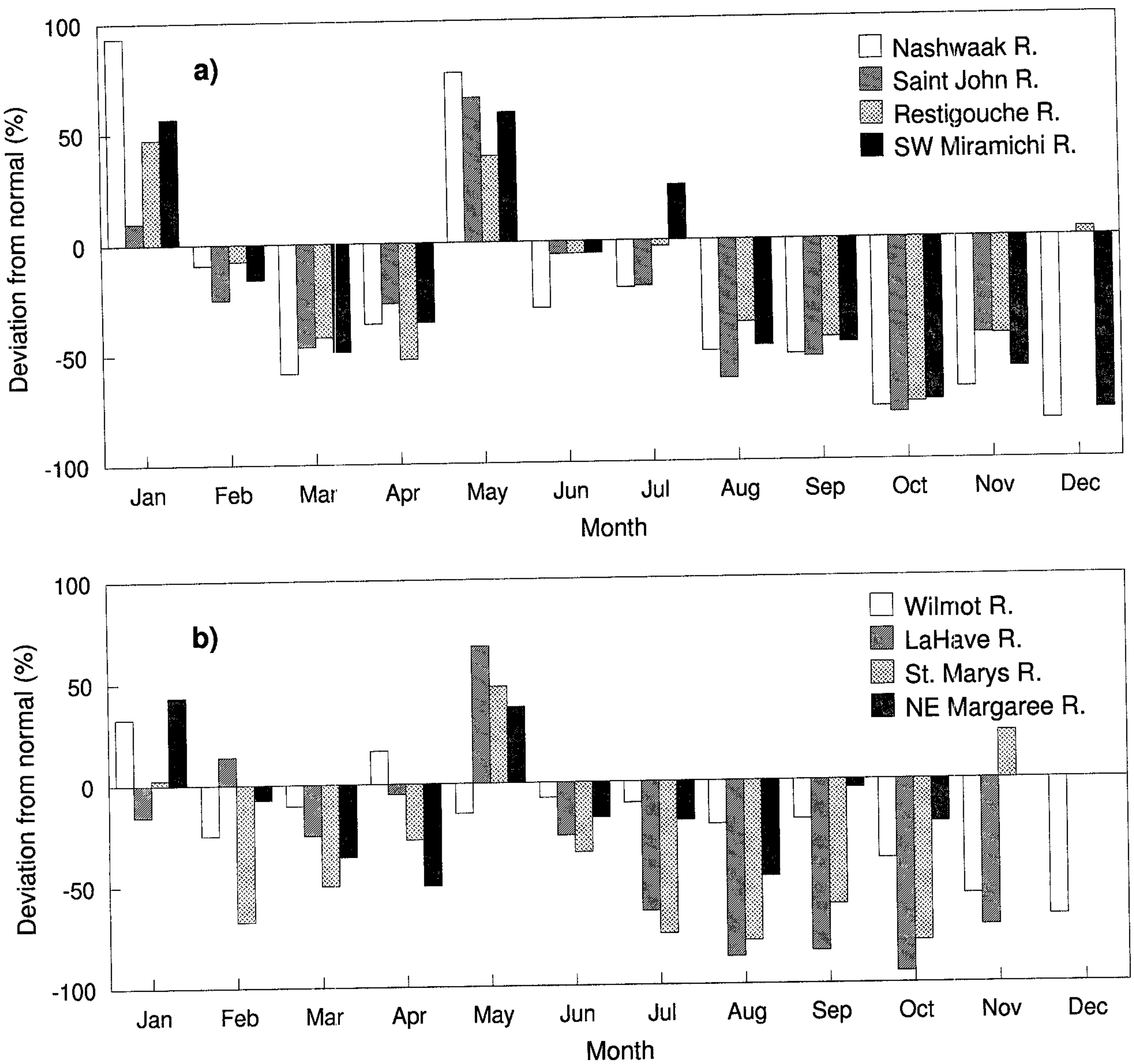


Figure 2. Deviation from mean monthly discharge in 1997 (in percentage, %) for studied rivers in the Maritime provinces.

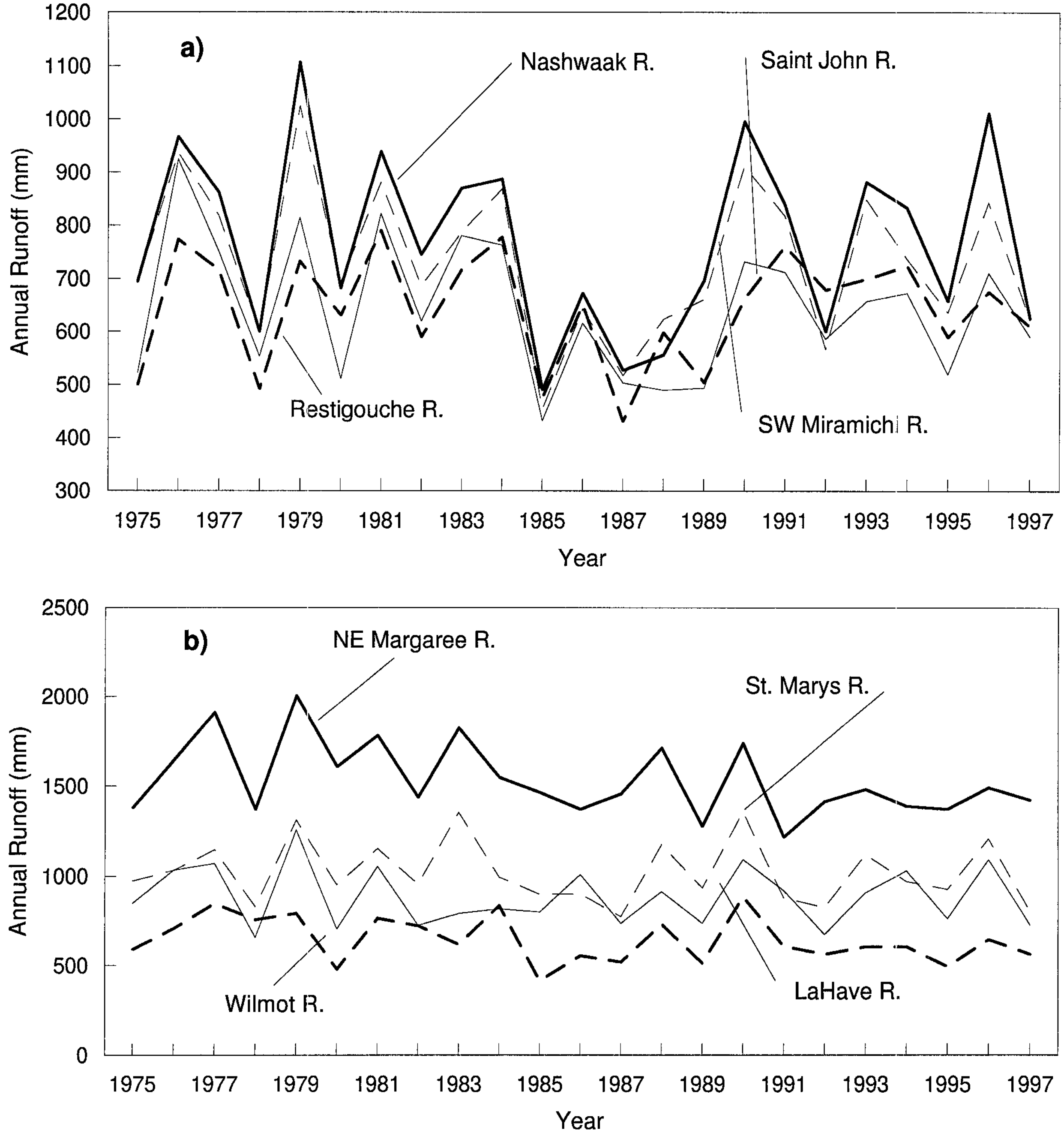


Figure 3. Mean annual runoff (mm) for Atlantic salmon rivers in the Martime provinces between 1975 and 1996.

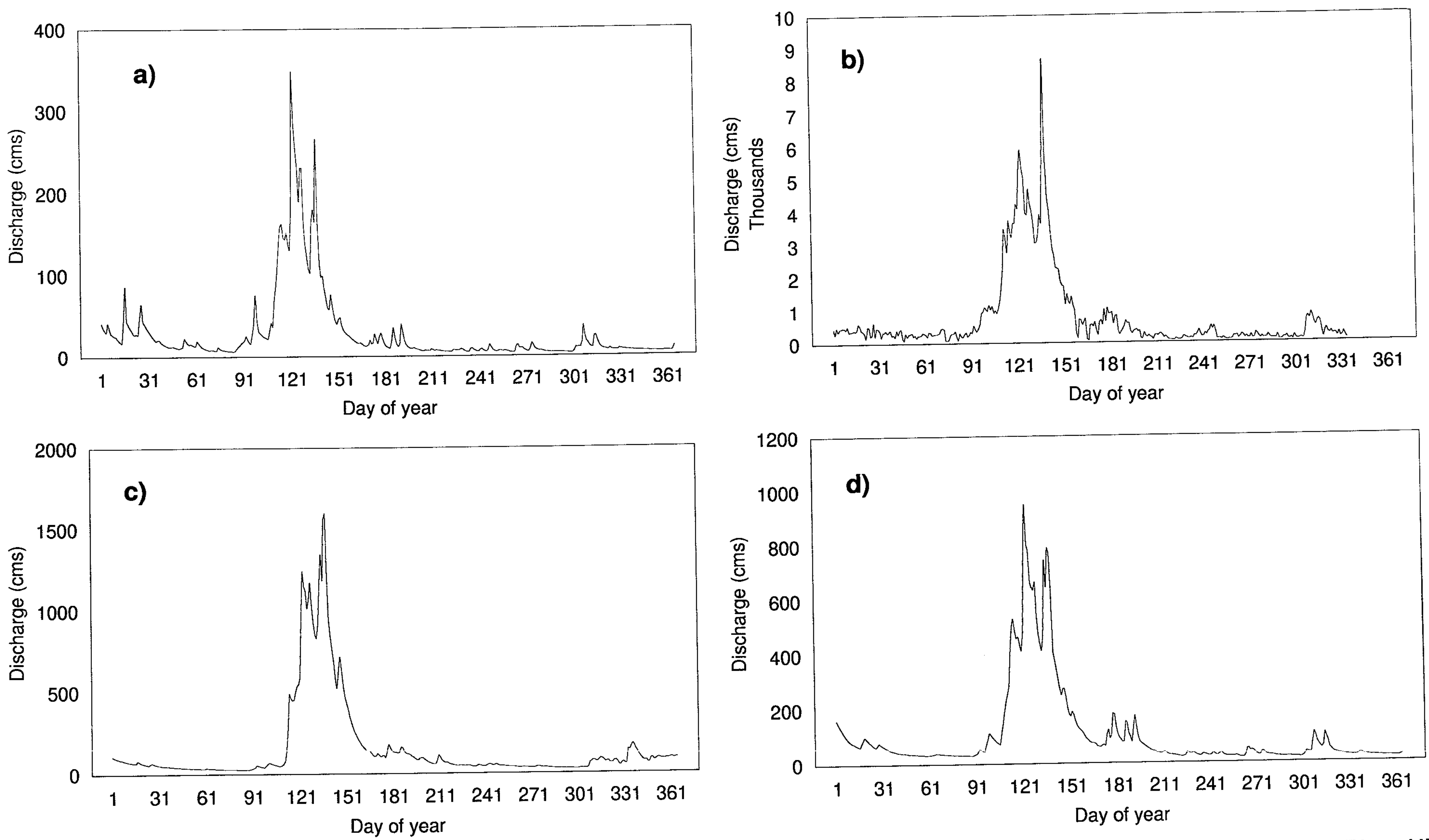


Figure 4. Daily stream discharge (cms=m^3/s) for selected rivers in the Martime Provinces in 1997: a) Nashwaak River, NB; b) Saint John River, NB; c) Restigouche River, NB; and d) Southwest Miramichi River, NB.

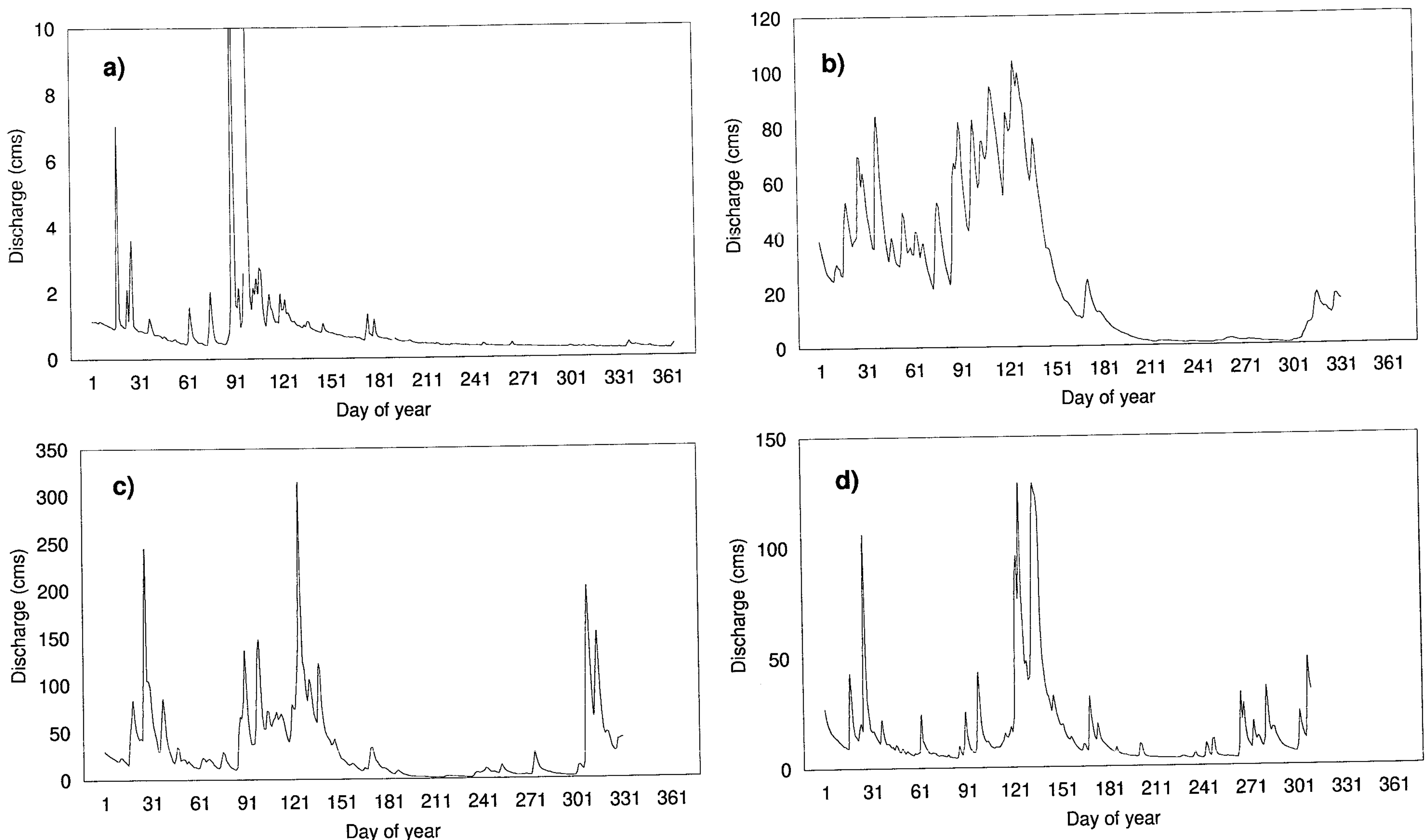
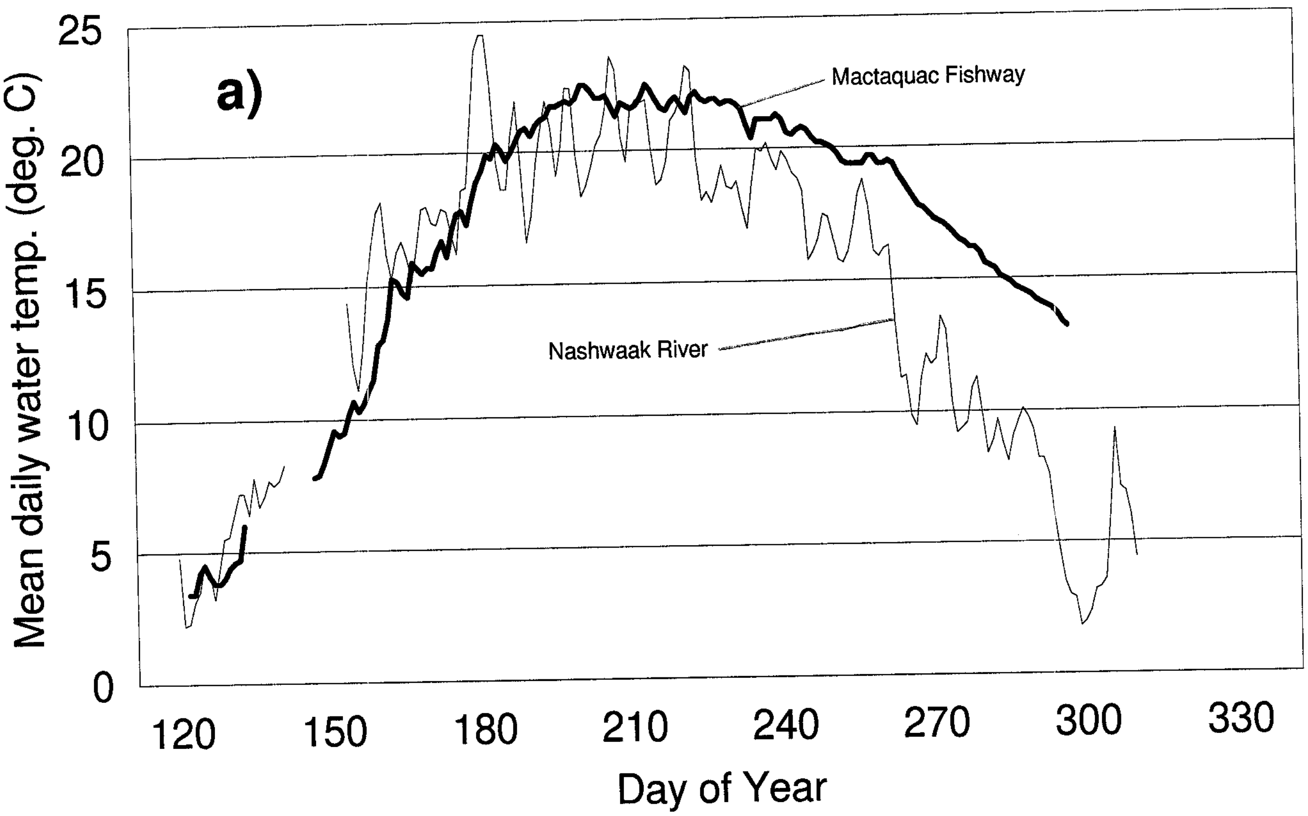


Figure 5. Daily stream discharge (cms=m^3/s) for selected rivers in the Maritime Provinces: a) Wilmot River, PEI; b) LaHave River, NS; c) St. Marys River, NS; and d) Northeast Margaree River, NS.



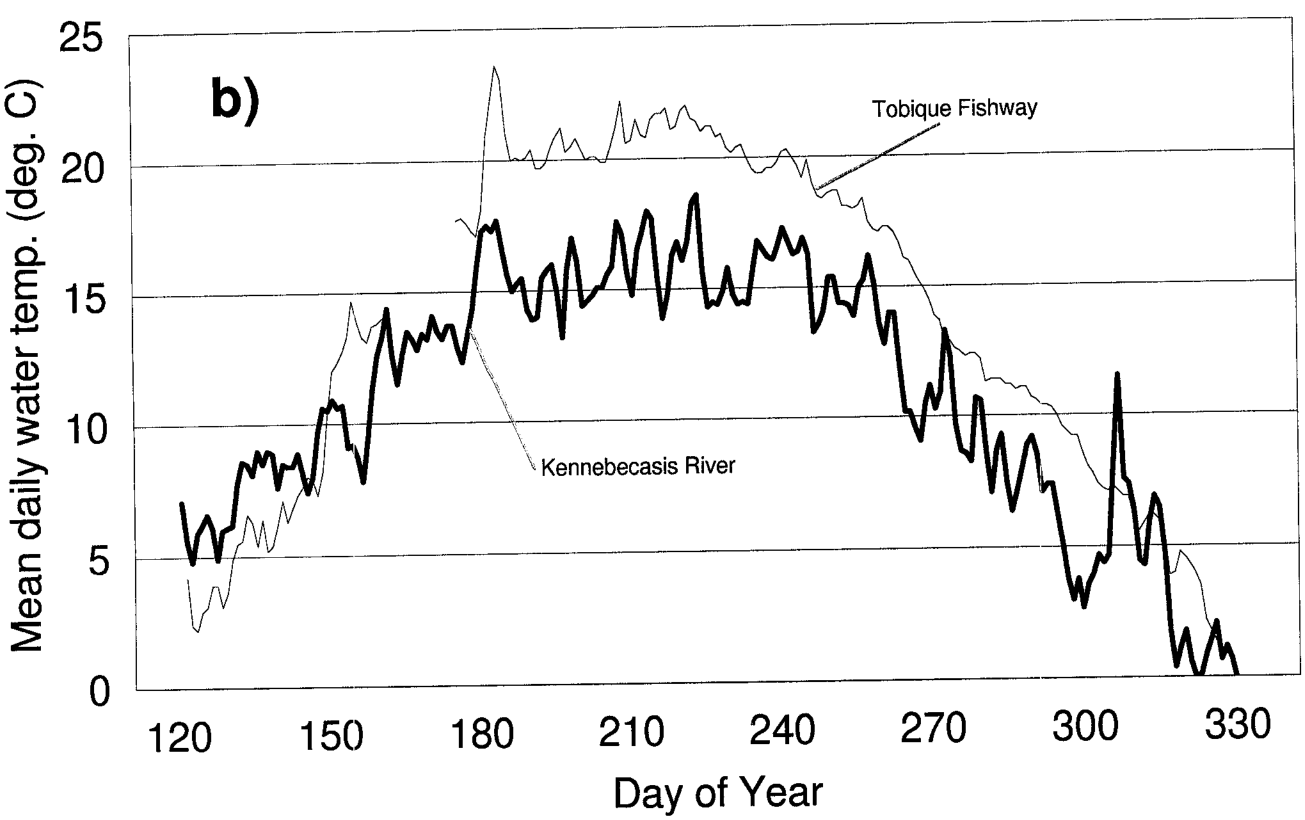
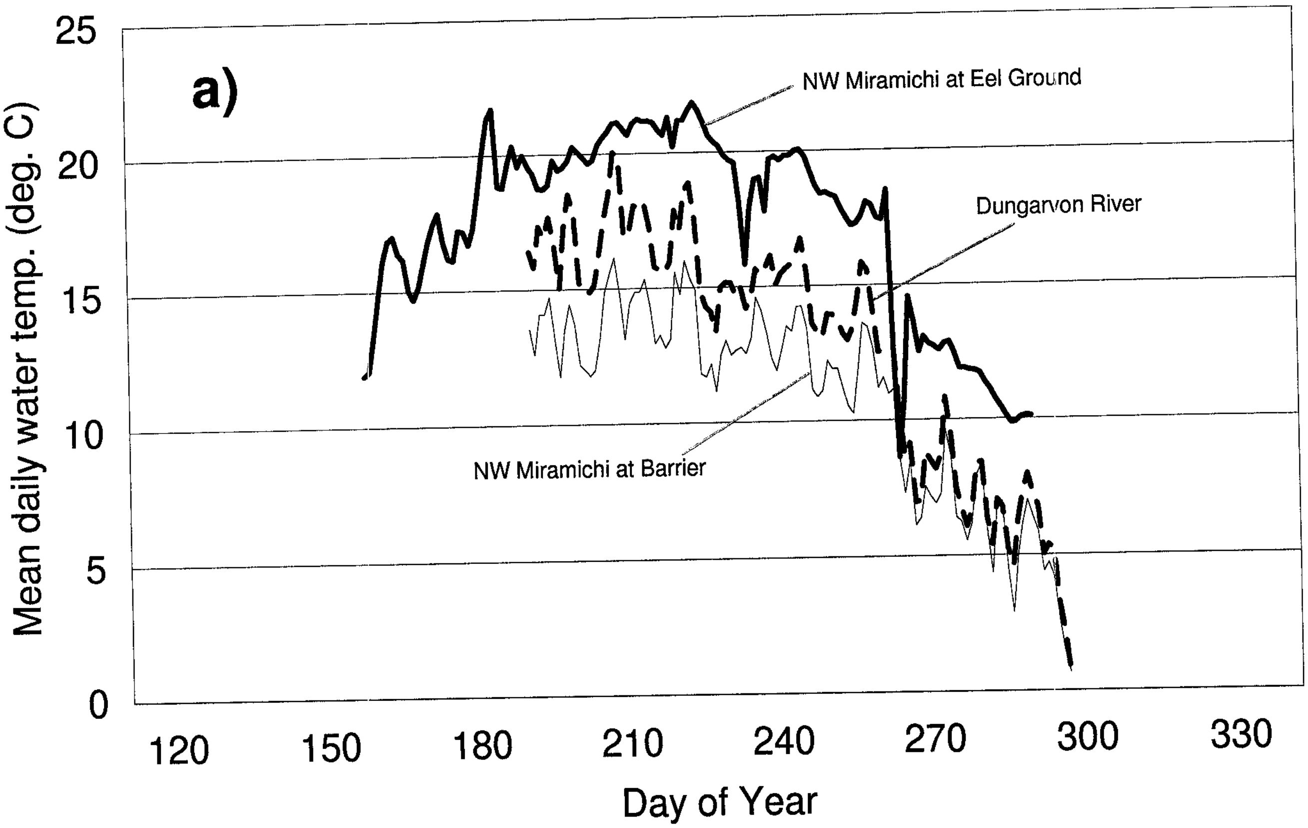


Figure 6. River water temperature at four locations from rivers in New Brunswick in 1997. (Day 120 = April 29)



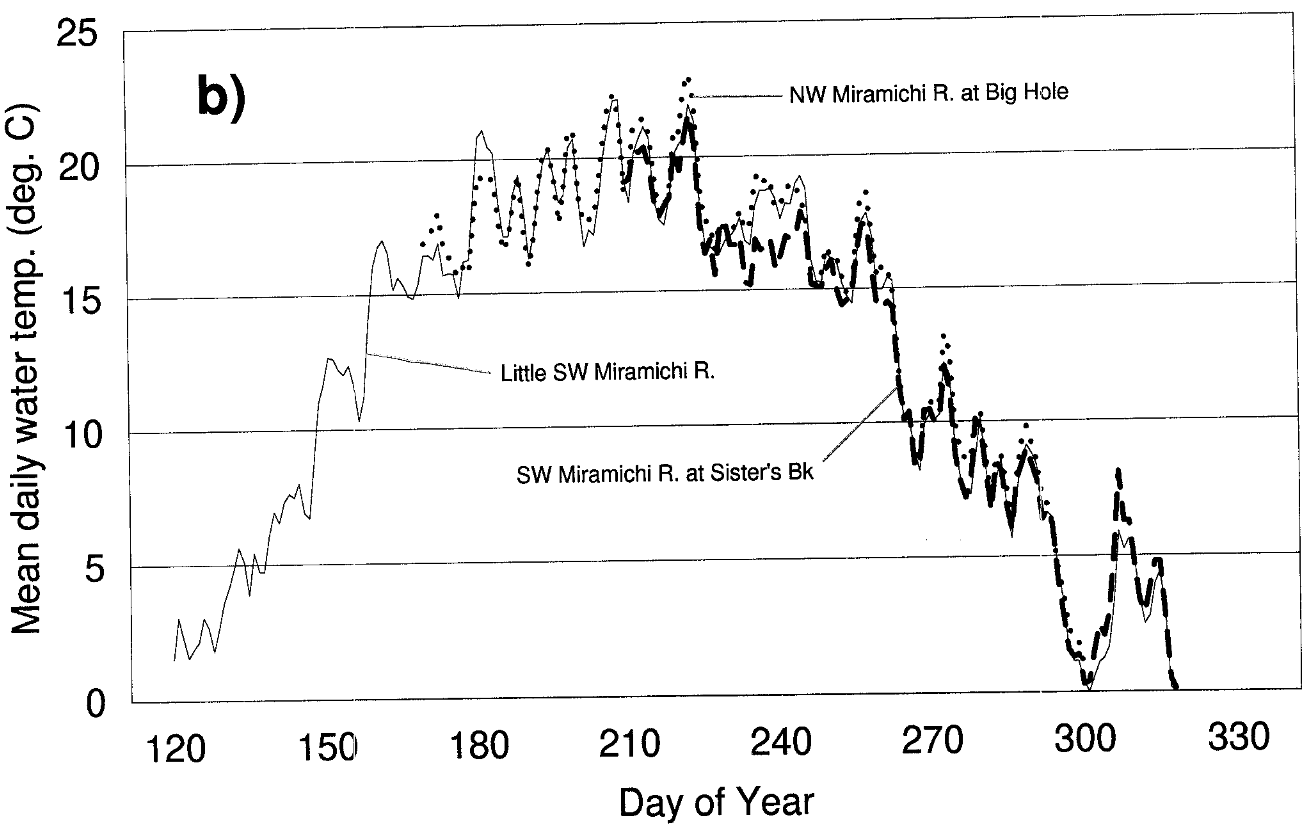


Figure 7. River water temperature for 6 locations within the Miramichi River basin in 1997. (Day 120 = April 29)

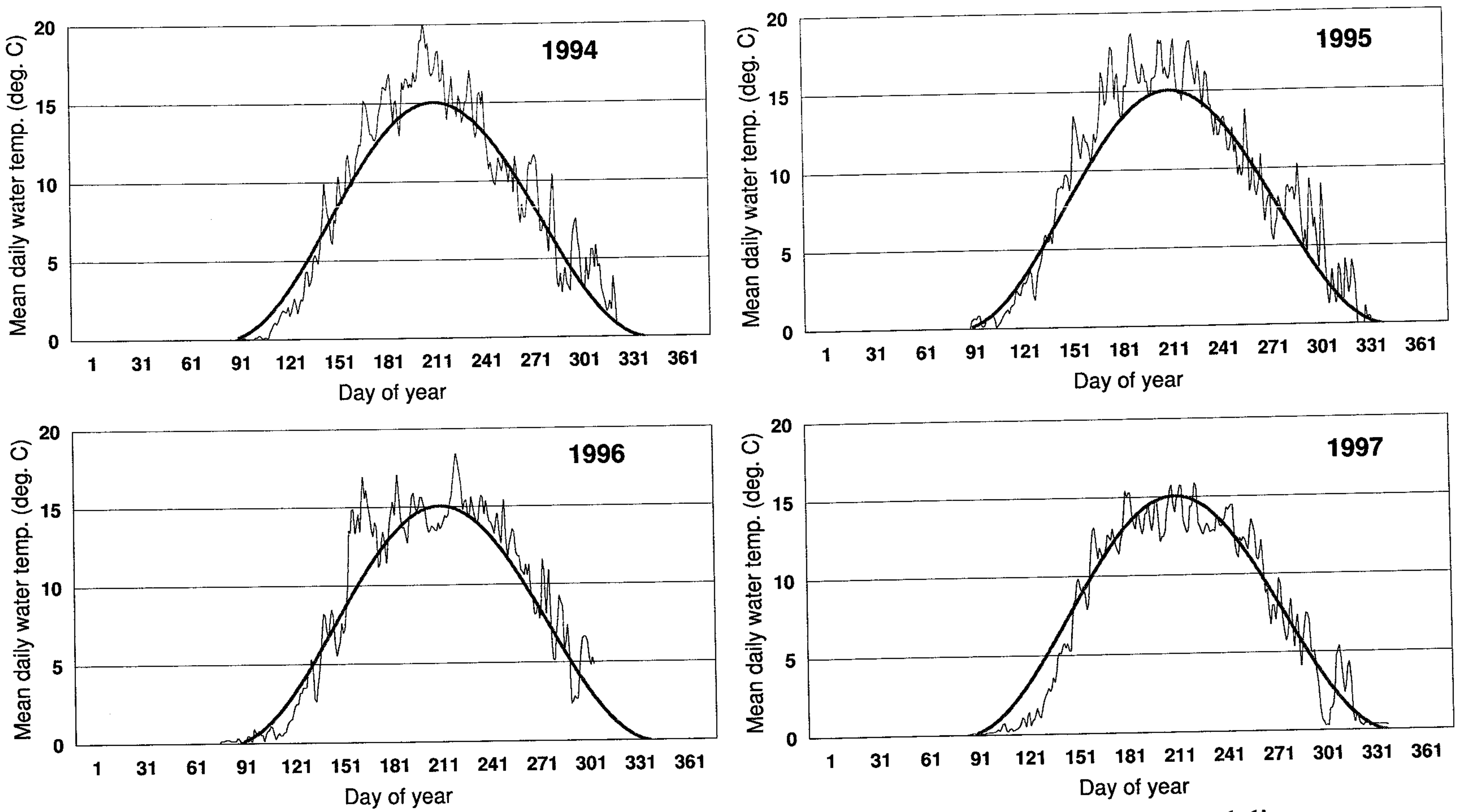


Figure 8. Stream water temperature at Catamaran Brook (Middle Reach) from 1994 to 1997; smooth line represents long-term temperatures.

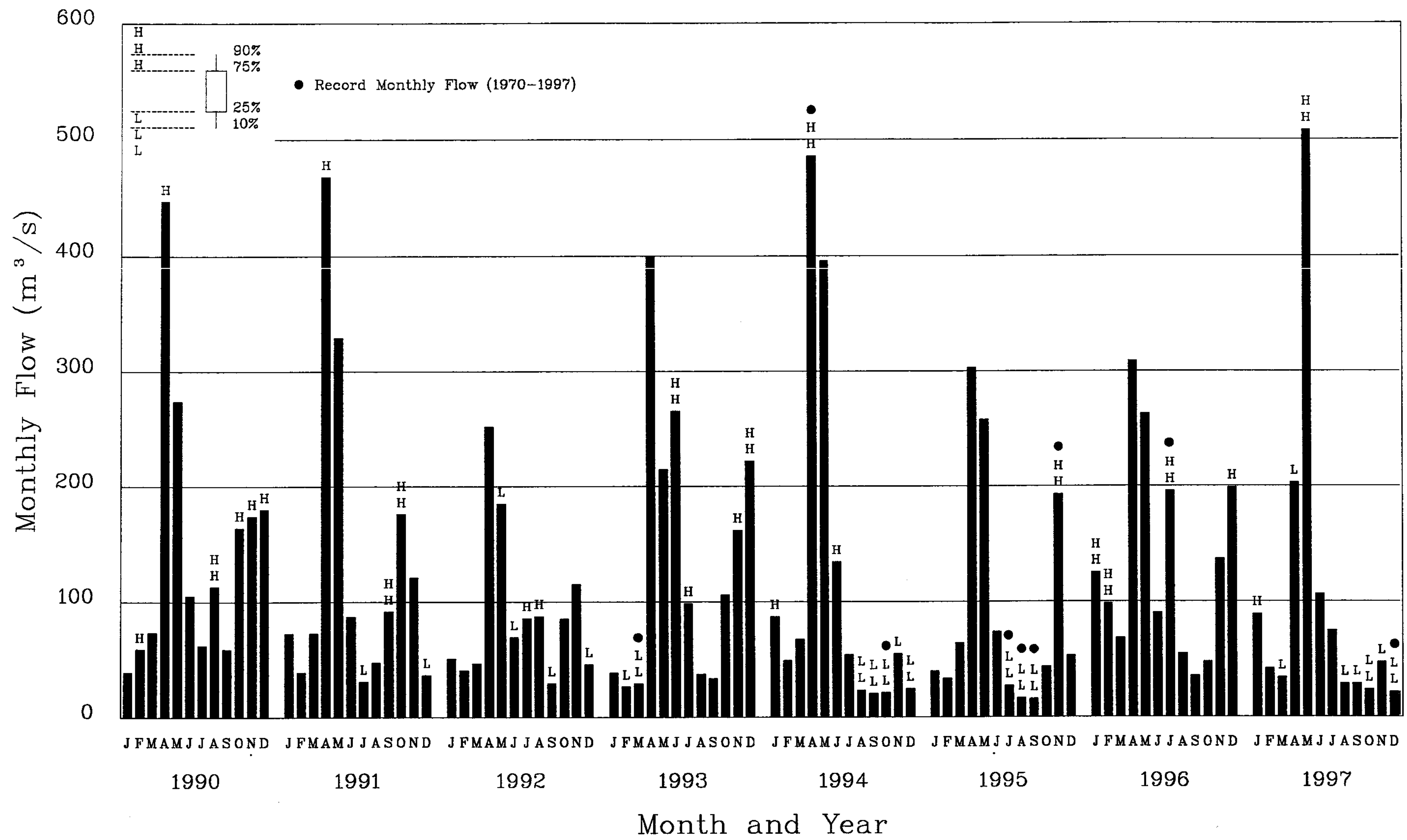


Figure 9. Southwest Miramichi River monthly discharges showing abnormally high and low water conditions between 1990 and 1997. L= Low; H= High; solid dots represent a record flow (1970–1997).

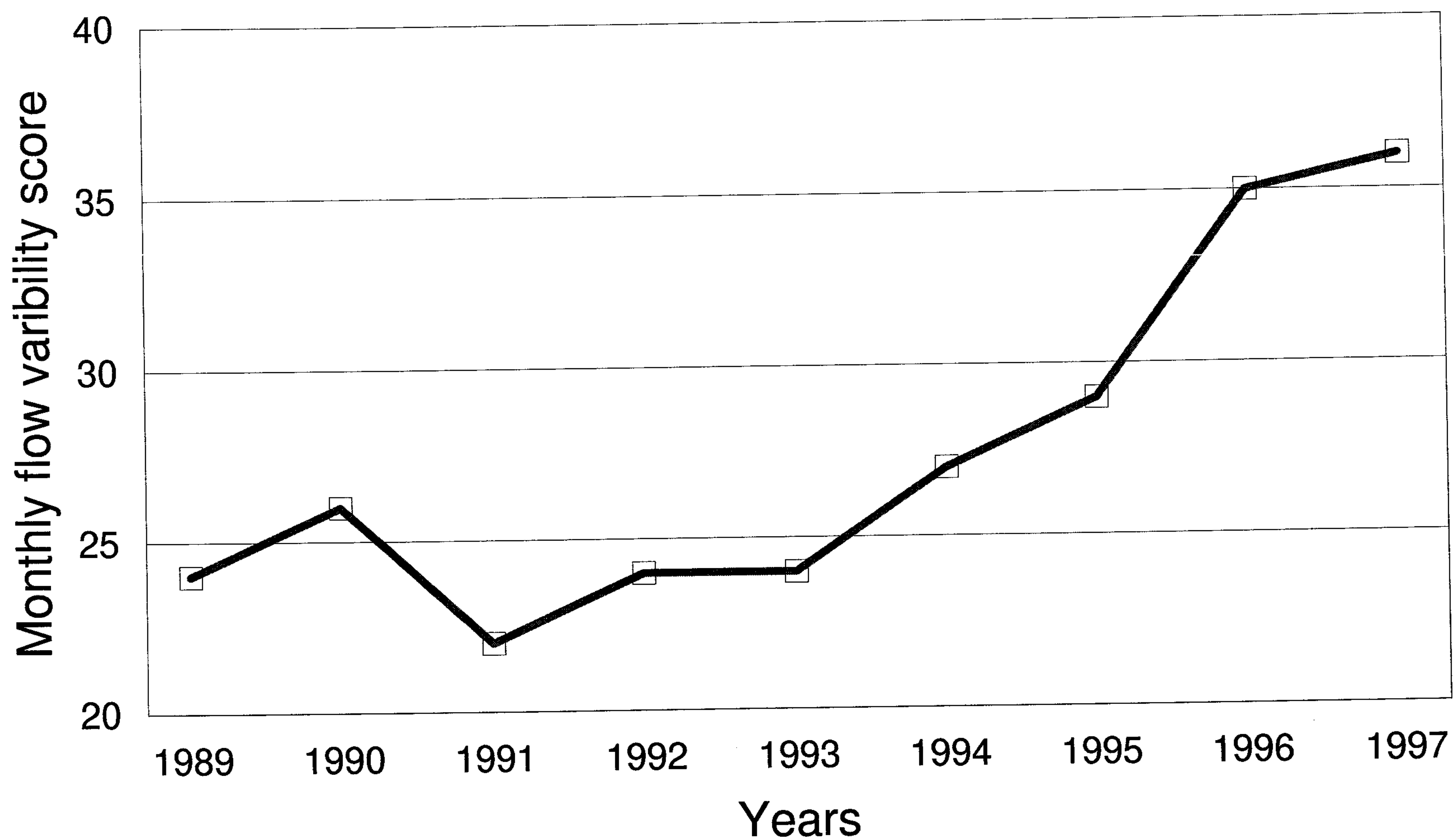


Figure 10. Summation of monthly flow variability score for freshwater life stage of Atlantic salmon (eggs deposition to smolt migration) for the Southwest Miramichi River, NB. Data for 1989 represents the summation of 1986 to 1989 flow variability score.

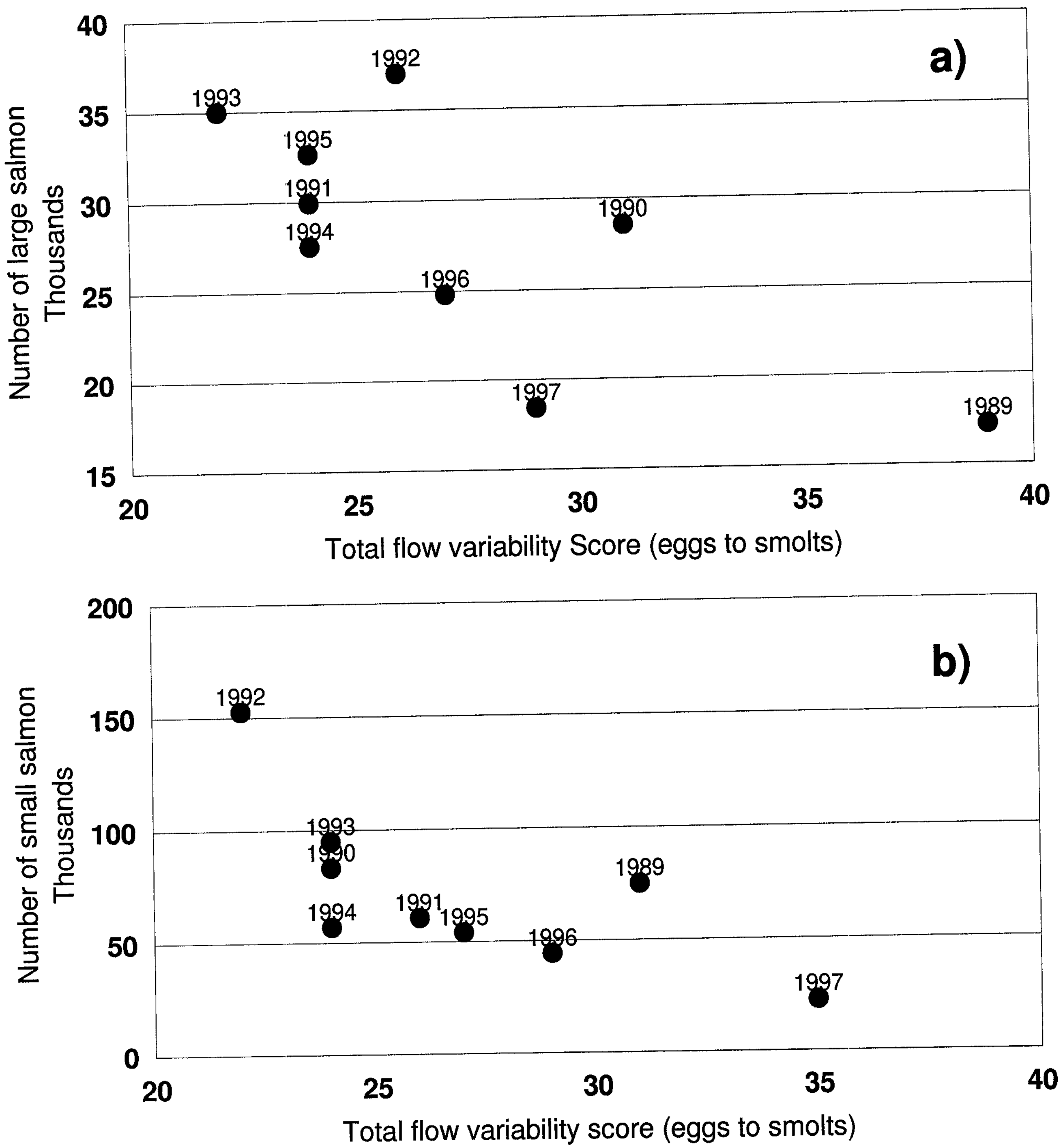


Figure11. Relation between returns of Atlantic salmon and the total flow variability score for the freshwater life stage (from egg deposition to smolt migration) for the Southwest Miramichi River, NB; a) Large salmon, b) Small salmon