Fisheries and Oceans Science | Pêches et Océans Sciences

C S A S | **S C É S**

Canadian Stock Assessment Secretariat | **Secrétariat canadien pour l'évaluation des stocks**

Research Document 2000/011 | **Document de recherche 2000/011**

Not to be cited without permission of the authors [1]

Ne pas citer sans autorisation des auteurs [1]

Hydrological Conditions for Atlantic Salmon Rivers in 1999

D. Caissie

Department of Fisheries and Oceans
Science Branch, Gulf Fisheries
P.O. Box 5030
Moncton, New Brunswick
E1C 9B6

[1] This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

[1] La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Research documents are produced in the official language in which they are provided to the Secretariat.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

This document is available on the Internet at:

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1480-4883
Ottawa, 2000

Canada

ABSTRACT

This paper provides 1999 and historical information on hydrological conditions for 6 selected Atlantic salmon (*Salmo salar*) rivers within the Maritime Provinces. High and low flows for each river were calculated based on historical annual high and low flow series. Air temperature data was presented for 6 stations in the Maritime Provinces. Stream water temperatures were reported in 3 river systems as well as high temperature events.

Discharges were excessive for most rivers in the winter of 1999 (January and March). Record high monthly flows were observed in March in St. Marys River (NS). The spring breakup of 1999 was early with peak flows in March. The spring breakup was generally characterized as mild with most rivers having floods less than a 2-year flood event. Upsalquitch River and Northeast Margaree River experienced the highest flood peaks close to the 5-year flood.

The early spring flood in 1999 resulted in low flow in June and July. Deficient monthly flows were observed in all rivers during these two months and record low monthly flows were monitored in both Wilmot River (PEI) and Northeast Margaree River (NS). On a daily basis, most rivers did not fall to the 2-year low flow this year. Southwest Miramichi River and Northeast Margaree River were the most affected in terms of low water conditions and they reached a 10-year low flow event.

River water temperatures in 1999 were characterized by five events between mid-June and late-August. Nashwaak, Little Southwest Miramichi, Tobique and Tomogonops Rivers all reached peak temperature exceeding 29 •C in 1999. These high water temperatures were the result of the highest summer air temperature on record in the Maritime Provinces (data going to 1940s). The number of days with river water temperatures exceeding 23 °C, more than doubled this year. The most affected river was the Nashwaak River with 67 days of temperatures exceeding 23 °C. Of the 15 studied rivers, 7 rivers showed over 50 days with high temperatures (> 23°C).

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 1999. 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'air est présentée pour 6 stations dans les provinces Maritimes. La température de l'eau a été obtenue pour 3 rivières, et les caractéristiques de température, tel que les événements de température élevés, ont été présentées.

En général, le débit des rivières était supérieur à la normal pendant l'hiver 1999 (janvier et mars). En mars, un débit mensuel extrême fut observé sur la rivière St. Marys (NE). La débâcle en 1999 était plus avancée que la normale avec des débits de crues en mars. Les débits de crue au printemps étaient assez faibles et de l'ordre de 2 années de récurrence. Quelques rivières démontrèrent un débit de crue plus fort tel que la rivière Upsalquitch et la rivière Northeast Margaree avec un débit d'une récurrence d'environ 5 années.

Les débits élevés en hiver, suivi d'un printemps avancé, contribua aux débits faibles en juin et juillet. En effet, des conditions de débits inférieurs à la normale ont été observées dans toutes les rivières durant ces mois. Des conditions de débits faibles extrêmes furent observées sur les rivières Wilmot (IPE) et Northeast Margaree (NE) durant le mois de juin. Sur une base journalière, les débits faibles de la plupart des rivières étaient supérieurs au débit d'une récurrence de 2 années. Les débits faibles des rivières Southwest Miramichi et Northeast Maragree étaient plus sévères avec une récurrence de l'ordre de 10 années.

Les variations dans la température de l'eau en 1999 peuvent être caractérisées par 5 événements importants à partir de la mi-juin jusqu'à la fin août. Les rivières Nashwaak, Little Southwest Miramichi, Tobique, et Tomogonops ont atteint des températures supérieures à 29 °C en 1999. Ces températures extrêmes étaient le résultat de températures de l'air estival qui eux aussi étaient extrêmes (données qui datent jusqu'à 1940). Le nombre de jours avec des températures de l'eau supérieurs 23 °C a doublé cette année. La rivière le plus sévèrement affectées était la rivière Nashwaak avec 67 jours de température supérieure à 23 °C. Des 15 rivières étudiées, 7 ont démontré plus de 50 jours de température élevée (> 23°C).

INTRODUCTION

An understanding of hydrological conditions can be important in the management of fisheries and aquatic resources. Some events such as streamflow variability and high water temperature can affect stream biota at different life stages and also during different seasons of the year. Salmonids can be affected by stream discharge extremes such as high flows (Elwood and Waters 1969; Erman *et al.* 1988) or during low flows, the latter being often associated with high river water temperatures (Cunjak *et al.* 1993; Edwards *et al.* 1979). In order to increase our knowledge of environmental conditions of particular Atlantic salmon rivers for the purpose of assessing Atlantic salmon stocks, we need to study the stream hydrology for these rivers and associated extreme events.

The objective of the present study is to analyze regional hydrological data for important Atlantic salmon rivers within the Maritime Provinces for use in aquatic resource management. The specific objectives are: a) to provide an overview of the monthly precipitation at 6 sites and flow conditions for 6 rivers, b) to determine the high and low flow months in 1999, c) to determine the frequency of floods and low flow events in 1999, d) to identify abnormal streamflow events in the Maritimes Region, and e) to analyze data on air and water temperature events for some salmon rivers in the area.

METHODS

Historical and 1999 data on precipitation were obtained from Environment Canada for 6 sites in the Maritime Provinces and monthly precipitation data were presented.

Regional hydrological analysis was carried out using historical hydrometric data from gauged streams and rivers in the study region. The 1999 hydrometric data were obtained from Environment Canada, while historical data were obtained from publications (Environment Canada 1990). 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 low flow events occur 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).

Monthly flow characteristics for 1999 were compared to long-term monthly 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).

Water temperatures were studied for 15 sites throughout the Maritime Provinces. Mean daily water temperature values as well as peak temperatures were considered in the analysis. Also, the number of days which each river exceeded 23 •C was analyzed.

Study rivers

The study region comprises 6 Atlantic salmon rivers within the Maritime Provinces for hydrological studies and 15 water temperature sites (Figure 1). These rivers are: Upsalquitch River (01BE007, 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 5050 km^2 (Southwest Miramichi 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 116 m^3/s for the Southwest Miramichi 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 (NB) and Prince Edward Island (PEI) showed the lowest runoff with only 640 mm (Wilmot, PEI) and 568 mm (Upsalquitch River, NB) compared to more than double this value at 1485 in Cape Breton (Northeast Margaree River) Nova Scotia (NS). The precipitation varies from 1080 mm in Northern New Brunswick to 1600 mm in Cape Breton (NS) (Table 1). The coefficient of variation (CV) of monthly flow characteristics showed more stable flow regime 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 Upsalquitch River with a CV of 1.01 (Table 1).

RESULTS

PRECIPITATION IN 1999

Long-term precipitation data (1953-1990) are presented in Table 2 for comparative purposes. The highest monthly precipitation in 1999 was recorded in Charlo in September with a total value of 293 mm. In contrast, the lowest precipitation recorded in the region was also in Northern New Brunswick at Charlo with a precipitation in May of only 25.3 mm. Most areas showed above average precipitation in March of 1999 and in New Brunswick in September (Table 2). The September high values in New Brunswick were due to the passing of tropical storm Floyd in the area. The Maritime Provinces showed below average precipitation in June and in May for some sites in NB. Other months showed close to average precipitation in 1999.

HYDROLOGICAL CONDITIONS IN 1999

In general, winter flows (January and March of 1999) were excessive (Table 3a). Flows were excessive in all rivers in the Maritime Provinces during these two months. The greatest deviation from the long-term monthly flow was observed in New Brunswick and Nova Scotia with flows close to +200% (Southwest Miramichi R.; Northeast Margaree R. and St. Marys R. Figure 2). The St. Marys River experienced record flows in March, with flows of 146 m^3/s compared to a 55.3 m^3/s as average (Table 3a).

The spring high flow of 1999 was early with peak flows in March, resulting in average to deficient flows in April and May. In fact, many rivers were deficient in April and May of 1999 (Wilmot R., PEI; LaHave R. NS; St. Marys R., NS; Figure 2 and Table 3a). Record low flow was measured in PEI in April of 1999, with a discharge value of 0.88 m^3/s compared to the average value of 1.94 m^3/s.

Summer monthly flows in 1999 were characterized as deficient between May and August in most rivers. During June and July deficient flows were observed in all Maritime province rivers (Table 3a). Rivers in NS showed greater deviation from the average with values in the range of –75% (Figure 2). Record low flow was measured in June in the Southwest Miramichi River and Northeast Margaree River. The Southwest Miramichi River flow was at 36.4 m^3/s compared to a long-term average of 112 m^3/s. The recorded low flow in the Northeast Margaree River was observed at 3.16 m^3/s compared to the long-term average of 15.5 m^3/s. In August, low flows were predominately in NB and PEI, while NS rivers showed normal discharge.

In autumn, excessive flows were monitored in both September and October (Table 3a). In September these were mainly concentrated in NB and PEI, with a record high flow occurring in PEI. Wilmot River showed a record high value of 0.90 m^3/s compared to the long-term average of 0.43 m^3/s. Excessive flows were also monitored in October in Wilmot, LaHave, and Northest Margaree Rivers (Table 3a; Figure 2).

On a daily basis, peak flows in the Maritime Provinces occurred in general earlier this year than in previous years. Most peak flows occurred in March, although peak flows occurred in January for NE Margaree (NS) and in Wilmot River (PEI). The river which experienced the latest peak flow was Upsalquitch River with a peak discharge on May 05 of 373 m^3/s (Table 3b). The peak flow for Upsalquitch River represents a flow higher than the 2-year flood (Table 4). Miramichi River (NB) experienced a peak flow of 580 m^3/s on March 31, which is less than a 2-year flood. Wilmot River (PEI) and LaHave River (NS) also experienced peak flows that were less than a 2-year flood. Peak flow in Wilmot River occurred on January 10 and the LaHave River peak flow occurred on March 17. St. Marys River experienced slightly higher than the 2-year flood with a peak flow on March 16 of 393 m^3/s. The river most severely affected by high flows in 1999 was Northeast Margaree River with a peak flow exceeding the 5-year flood at 234 m^3/s in January (Table 3b and Table 4). Daily peak discharges were also measured in September of this year, especially in New Brunswick.

On a daily basis, low flows were experienced in winter of 1999, particularly in Northern NB (Upsalquitch R.) and in Cape Breton (NE Margaree R.). The most severe low flow conditions in 1999 occurred during late summer, especially in September (Table 3b). The winter low flows were close to summer low flow conditions in some rivers. For instance, a flow of 7.15 m^3/s (Feb.) was monitored in Upsalquitch River and was comparable to the summer low flow of 5.18 m^3/s (Sept.). Also, flows were low in winter in Northeast Margaree River at 3.8 m^3/s (Jan.) but higher than summer values of 1.89 m^3/s in June. Rivers in NB experienced low flow more severe than the 2-year low flow. For instance, Upsalquitch River experienced 5.18 m^3/s on September 06, which was a discharge lower than the 2-year flow. In early September (06) the Southwest Miramichi River experienced a low flow of 12.3 m^3/s, below that of a 10-year event. Rivers in Nova Scotia and PEI for the most part monitored discharge higher than the 2-year low flow, except for NE Margaree which recorded a record daily low flow in June of 1.89 m^3/s. This flow is in the range of a 15-year low flow event.

In general, peak flows in 1999 were close to or below the 2-year flood event in the Martime Provinces except for NE Margaree River, which experienced higher peak flows than the 5-year event. For low water conditions this year, many rivers in the Maritime Provinces showed flows higher than the 2-year low flow. The two rivers most affected by low water conditions were the Southwest Miramichi River and Northeast Margaree River with flows lower than the 10-year event.

The occurrence of high and low flow events was studied for three rivers in the Maritime Provinces over 4 decades (1960 to 1999). Results on high and low flow events are presented in Table 6. Annual peak flows for Southwest Miramichi were highest in the 70s with 6 years having peak flow higher than 1000 m^3/s (flow higher than the 2-year flood). The 70s also showed a high occurrence of winter and June peak flows. Low flow events in the Miramichi were more important in the 60s and 90s each having 6 years with flow lower than 20 m^3/s (2-year low flow). Winter low flow can be important in the Miramichi with the occurrence of one or two low flow years per decade, and up to 60 days of low water conditions in 10 years (Table 6). The occurrence of low flow events was more important during the summer period, especially in the 60s and 90s with duration of over 100 days.

Data for St. Marys River showed that the 60s and 70s experienced the most years of peak flow having 7 years with peak flow higher than 400 m^3/s (close to a 2-year flood). The recent decades only showed 2 to 4 years. Winter peak flows are much higher in relative terms than those of New Brunswick. Results showed that winter peak flows have been important during the past 3 decades (Table 6). June high flow events were most important in the 70s with 5 years of peak flow in June higher than 100 m^3/s. Low flows in St. Marys River are predominately in summer and have been consistent throughout the decades. However, the duration of low flow conditions has been most important in the 70s with 116 days. LaHave River showed a consistent pattern in high flows with 4 to 5 years per decade. Winter and June high flows were more prevalent in the 70s. Low flow periods have predominately been observed in the 60s and 90s with 7 and 6 years respectively. The duration of low flow was twice as long in the 60s and 70s than for other decades.

AIR AND STREAM WATER TEMPERATURES

Air temperatures were obtained for 6 stations across the Maritime Provinces, at Charlo (NB), Chatham (NB), St John (NB), Charlottewon (PEI), Halifax (NS) and Sydney (NS). Mean annual air temperatures were calculated for all stations and the results are shown in Figure 3. In order to calculate the mean annual air temperature in 1999, an average monthly temperature was assumed for November and December (data not available for these months). From this figure it can be observed that air temperature varies depending on the location within the Maritime Provinces. Halifax showed the highest mean annual air temperature and Charlo had the lowest air temperatures. The Charlo time series is also shorter than data from the other stations. Because of the shorter time series at Charlo, mean values for the Maritime Provinces will be calculated with and without Charlo.

The mean annual air temperature was calculated for the Maritime Provinces for the year and during the summer only (Figure 4). It was observed that the overall mean annual air temperature was close to 5 •C for the year (Figure 4). This figure showed a relatively warm period in the early 50s, with temperatures higher than 5 •C and thereafter they became close to 5 •C again. The last 2 years (1998 and 1999) have been higher than normal with temperatures of 6.5 °C and 7.1•C. The summer (from May to September) temperatures can also be of interest for fisheries resources and they are also presented in Figure 4. The mean summer air temperature varied between 13.2 •C and 15.9 •C. Summer air temperatures have been below 15 •C since the early 60s, except for 1998 and 1999 when values exceeded 15 •C. In fact, the highest temperature since the early 40s was measured in 1999 at 16.9 •C.

River water temperatures were available at 15 sites within the Maritime Province in 1999. The high water temperature events this year can be characterized by multiple events from June to the end of August as presented for sites in the Miramichi River (Figure 5). The first events occurred in June this year (June 14; day 165 and June 26; day 177). July experienced the highest water temperature event of the summer on or about July 18 (day 199). August also experienced two significant high water temperature events, the first on August 01 (day 213) and the second on August 28 (day 240).

During these high water temperature events, many rivers reached mean daily water temperatures of 25 °C in the Miramichi River (Figure 5). Such rivers included the Southwest Miramichi River at Cassilis, at Millerton, and at Wade. The Little Southwest River also reached mean daily temperatures of 25 °C. Water temperatures at other sites in New Brunswick showed a similar pattern, with maximum temperatures in late July (day 199; Figure 6). Temperatures exceeding 25°C were monitored in both the Nashwaak and Tobique River sites. The Kennebecasis River site showed colder water temperatures throughout the summer season. The Mactaquac Fishway site showed more stable thermal regime as was observed in previous years (Caissie 1999a; Caissie 1999b). Prince Edward Island water temperature sites showed results similar to those in New Brunswick with the highest temperatures reached in late July (day 199; Figure 7).

Maximum recorded temperatures are important for most rivers, and they are presented in Table 7. Maximum recorded temperatures in the Miramichi River system in 1999 ranged between 24.5 •C at Catamaran Brook to 29.9 •C in the Little Southwest Miramichi River. Other rivers in New Brunswick reached similar values, except for Tobique River at Arthurette, which reached a high of 30.6 °C. In PEI, rivers reached high water temperatures of 23 °C to 26°C. The maximum water temperature was reached on July 17 or 18 for most rivers.

High temperature events can potentially effect aquatic biota depending on the recorded maximum temperature and the extent of such events. The last column in Table 7 presents the number of days with daily maximum temperature exceeding 23 •C. The number of days with water temperatures exceeding 23 •C ranged from 2 to 67 days in the Maritime Provinces in 1999. Rivers with fewer than 10 days included Catamaran Brook, Kennebecasis River, and Morell River at Grants. These are the rivers which are less affected by high water temperature events. Other rivers were more affected by high water temperatures. In 1999, many rivers experienced high water temperatures (> 23°C) for more than 2 months (60 days). These sites included Little Southwest Miramichi River, Southwest Miramichi River at Millerton, at Wade, and at Cassilis. The highest number of days in the Miramichi River system was observed at Little Southwest Miramichi River with 62 days (Table 7). Other high water temperature sites in New Brunswick included Tobique River and Nashwaak River. Nashwaak River experienced the highest occurrence of temperature exceeding 23 •C with 67 days. When these numbers were compared to previous warm years (Caissie 1999a; Caissie 1999b), the occurrence of high water temperature events was almost double in 1999. For instance, in 1999 the Little Souhtwest Miramichi River exceeded 23 •C for 62 days compared to 16 days in 1998 (Caissie 1999b). Also Nashwaak River exceeded 23 °C for 67 days in 1999 compared to 30 days in 1998.

To compare water temperature in 1999 to previous years, the long-term data series from Catamaran Brook were used. Water temperatures have been collected at Catamaran Brook since 1991 (Table 8). Highest monthly water temperature to date was recorded in July 1994 at 16.6 •C. In 1999, this high was exceeded during two months, July and August. The highest monthly temperature was recorded in July at 17.2 •C compared to a mean of 14.5 •C. Monthly temperatures were higher than normal for all months from April to October. Figure 8 shows the daily mean temperatures at Catamaran Brook in 1999. This figure clearly shows the above normal water temperature this year compared to previous years. Water temperatures rose above normal in early May (day 121) and stayed above normal until late September (day 271).

SUMMARY

In summary, the streamflow conditions during 1999 were characterized by an earlier spring runoff in March, which resulted in very low monthly flow for June. Record low monthly flows were observed in June for Southwest Miramichi River and Northeast Margaree River.

The spring runoff in 1999 was characterized as mild in most rivers with peak flows less than the 2-year flood with the exception of Upsalquitch and Northeast Margaree rivers. Upsalquitch River discharge exceeded the 2-year flood and the Northeast Margaree recorded the highest return flow at a 5-year flood event. Peak flows for many rivers occurred in January to March this year which was early.

Low flows were not severe in PEI and part of NS with discharge higher than the 2-year low flow. Rivers in NB experienced lower flows with Southwest Miramichi River have a discharge lower than the 10-year low flow in September. Northeast Margaree River also experienced lower discharge than the 10-year event in late June.

Mean air temperatures in 1999 were the highest in the time series, which dates back to the 40s for many stations. Many stations within the Maritime Provinces recorded their highest summer air temperature ever. These high air temperatures resulted in water temperatures also being high.

High water temperature during the summer of 1999 were the highest recorded in recent years, however these maximum temperatures were close to previous warm summers (e.g. 1994, 1995). The year 1999 was different in the number of days which temperatures exceeded 23 •C. In fact, many rivers exceeded 23 •C for over 50 days, with Little Southwest Miramichi River and Nashwaak River having the highest values at 62 and 67 days respectively. Compared to previous warm years the high water temperature events in 1999 were more than doubled in occurrences.

ACKNOWLEDGMENTS

The author would like to thank the following people for the contribution in the present study: G. Chaput, D. Moore, J. Haward, R. Jones and D. Cairns 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).

REFERENCES

Caissie, D. 1999a. *Hydrologcial conditions for Atlantic Salmon Rivers in the Maritime Provinces in 1997*. DFO Atlantic Fisheries Research Document 99/188. 34p.

Caissie, D. 1999b. *Hydrologcial conditions for Atlantic Salmon Rivers in the Maritime Provinces in 1998*. DFO Atlantic Fisheries Research Document 99/189. 31p.

Cunjak, R.A., D. Caissie, N. El-Jabi, P. Hardie, J.H. Conlon, T.L. Pollock, D.J. Giberson, and S. Komadina-Douthwright. 1993. *The Catamaran Brook (New Brunswick) Habitat Research Project: Biological, Physical and Chemical Conditions (1990-1992).* Canadian Technical Report of Fisheries and Aquatic Sciences 1914: 81p.

Edwards, R.W., J.W. Densen, and P.A. Russell. 1979. *An assessment of the importance of temperature as a factor controlling the growth rate of brown trout in streams*, Journal of Animal Ecology 48: 501-507.

Elwood, J.W., and T.F. Waters. 1969. *Effects of flood on food consumption and production rates of a stream brook trout population*. Transactions of the American Fisheries Society, 98: 253-262.

Environment Canada. 1990. *Historical Streamflow Summary: Atlantic Provinces*. Inland Waters Directorate, Water Resources Branch, Ottawa, 294p.

Environment Canada. 1995. *Surface Water Quantity Conditions - Atlantic Canada*. Ecosystem Science Division, Environmental Science Centre, Moncton, NB, Monthly Report.

Erman, D.C., E.D. Andrews and M. Yoder-Williams. 1988. *Effects of winter floods on fishes in the Sierra Nevada*. Canadian Journal of Fisheries and Aquatic Sciences, 45: 2195-2200.

Kite, G.W. 1978. *Frequency and risk analysis in hydrology*. Water Resources Publications, Fort Collins, Colorado, 224p.

Table 1. Characteristics of analyzed Atlantic salmon rivers in the Maritime Provinces.

River	Area[1] (km^2)	N (years)	MAF (m^3/s)	Runoff (mm)	CV	Prec. (mm)
Upsalquitch River (NB)	2270	69	40.8	568	1.01	1080
Southwest Miramichi R. (NB)	5050	51	116	725	0.82	1090
Wilmot River (PEI)	45.4	28	0.922	640	0.49	1100
LaHave River (NS)	1250	83	34.4	870	0.59	1420
St. Marys River (NS)	1350	83	43.0	1007	0.54	1350
Northeast Margaree R. (NS)	368	82	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 monthly precipitation (mm) and conditions in 1999 for different areas in the Maritime Provinces. (First row of data represents the long-term precipitation while the second row represents the condition in 1999).

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
	1999	100.8	77.6	185.2	44.8	87.8	36.3	102.6	102.1	205.9	n/a	n/a	n/a	
Charlo A (NB)	*LT*	89.3	63.9	84.4	76.6	87.2	84.3	98.6	98.5	89.4	90.0	87.0	97.4	1039
	1999	98.3	72.4	190.1	39.5	25.3	78.3	116.1	86.5	292.8	n/a	n/a	n/a	
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
	1999	164.4	101.9	136.6	31.6	83.2	31.5	58.5	95.7	229.8	n/a	n/a	n/a	
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
	1999	97.3	61.7	112.3	55.1	26.0	32.7	76.7	123.0	117.9	n/a	n/a	n/a	
Sydney (NS)	*LT*	143.5	126.3	129.7	113.4	101.5	87.1	82.8	97.3	107.0	125.7	154.0	152.2	1417
	1999	174.0	214.6	253.8	162.4	51.4	52.2	118.8	100.8	47.8	n/a	n/a	n/a	
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
	1999	159.5	109.6	237.4	59.3	58.6	44.7	56.9	89.1	121.3	n/a	n/a	n/a	

Table 3a. Long-term monthly and 1999 average flow conditions for different Atlantic salmon rivers in the Maritime Provinces. (First row of data for each river represents the long-term flow condition while the second row represents the 1999 discharges expressed in m^3/s).

River		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upsalquitch River (NB)	LT	14.0	10.8	13.2	88.6	158	53.8	25.7	18.7	17.9	27.2	34.7	25.8
	1999	21.7E	12.4	17.8E	110	142	22.8D	10.9D	8.41D	34.8E	37.4	n/a	n/a
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
	1999	81.1E	73.4	196E	392	177D	36.4DR	26.0D	28.6D	93.8E	119	n/a	n/a
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
	1999	2.14E	0.752	2.14E	0.881DR	0.716D	0.469D	0.399D	0.384D	0.898ER	0.936E	n/a	n/a
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
	1999	57.0E	29.0E	91.5E	34.3D	16.6D	5.9D	2.32D	7.05	21.0E	33.6E	n/a	n/a
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
	1999	66.2E	35.9	146ER	55.7D	24.5D	4.4D	5.76D	10.3	14.1	40.9	n/a	n/a
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
	1999	27.4E	11.3	34.8E	23.3	24.0D	3.16DR	3.81D	11.6	8.25	23.3E	n/a	n/a

D= Deficient flow; E = Excessive flow; R = New record flow (see text for more details).

Table 3b. Daily maximum and minimum flow conditions by month for different Atlantic salmon rivers in the Maritime Provinces. (discharges expressed in m^3/s).

River		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Upsalquitch River (NB)	Min	15.9	7.15	8.9	31.3	36.9	12.9	7.36	6.09	5.18	24.4	30.0	n/a
	Max	29.9	17.5	44.0	256	373	43.4	25.3	21.3	99.6	56.2	94.2	n/a
SW Miramichi R. (NB)	Min	30.0	38.5	36.5	221	85.2	20.7	19.1	16.1	12.3	63.4	79.4	n/a
	Max	262	116	580	527	375	69.3	43.6	108	508	267	305	n/a
Wilmot River (PEI)	Min	0.68	0.44	0.57	0.74	0.61	0.39	0.36	0.34	0.33	0.89	0.57	n/a
	Max	11.2	1.57	10.9	1.41	0.87	0.56	0.48	0.60	9.8	1.35	0.86	n/a
LaHave River (NS)	Min	19.8	16.0	30.7	17	8.22	2.78	1.97	2.1	1.95	15.8	12.4	n/a
	Max	103	54.8	153	77	33.8	14.0	2.98	21	110	65.0	48.0	n/a
St. Marys River (NS)	Min	21.0	16.9	47.0	28.8	9.46	2.2	2.0	1.89	1.98	12.0	16.9	n/a
	Max	182	105	393	110	71.8	9.26	34.3	48.6	37.7	105	68.0	n/a
NE Margaree River (NS)	Min	3.8	5.4	9.62	11.2	6.30	1.89	2.0	2.06	3.29	6.1	7.29	n/a
	Max	234	32.8	129	81.8	52.7	5.46	21.0	91.2	30.3	93.9	121	n/a

Table 4. Flood frequency analysis (using a 3-parameter lognormal distribution function) for different Atlantic salmon rivers in the Maritime Provinces and for different recurrence intervals (T) in years. All flood flows are expressed in m^3/s.

	Recurrence interval (T) in years					
River	2	5	10	20	50	100
Upsalquitch River (NB)	354	479	552	617	695	750
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. Low flow frequency analysis (using a Extremal type III distribution function) for different Atlantic salmon rivers in the Maritime Provinces and for different recurrence intervals (T) in years. All discharge values of low flows are expressed in m^3/s.

	Recurrence interval (T) in years					
River	2	5	10	20	50	100
Upsalquitch River (NB)	5.52	3.99	3.32	2.85	2.42	2.20
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. Results on the number years with high flow and low flow events by decades. Values in parentheses represent the number of days within the decade with flows below the target value.

			Southwest Miramichi River			
Period	**Annual Q>1000 m³/s**	**Winter Q>250 m³/s**	**June Q>250 m³/s**	**Annual Q<20 m³/s**	**Winter Q<20 m³/s**	**Summer Q<20 m³/s**
1960-69	2	0	2	6	2 (44)	5 (126)
1970-79	6	5	3	3	0 (0)	2 (27)
1980-89	3	2	2	3	2 (60)	2 (34)
1990-99	3	3	1	6	1 (13[a])	5 (119[a])
			St. Marys River			
Period	**Annual Q>400 m³/s**	**Winter Q>300 m³/s**	**June Q>100 m³/s**	**Annual Q<1.6 m³/s**	**Winter Q<1.6 m³/s**	**Summer Q<1.6 m³/s**
1960-69	7	0	1	5	0	5 (111)
1970-79	7	4	5	4	0	4 (116)
1980-89	2	4	1	2	0	2 (56)
1990-99	4	7	3	5	0	5 (70[a])
			LaHave River			
Period	**Annual Q>200 m³/s**	**Winter Q>150 m³/s**	**June Q>60 m³/s**	**Annual Q<1.6 m³/s**	**Winter Q<1.6 m³/s**	**Summer Q<1.6 m³/s**
1960-69	5	1	0	7	0	7 (390)
1970-79	5	5	3	4	0	4 (111)
1980-89	4	3	1	5	0	5 (129)
1990-99	5	5	2	7	0	7 (270[a])

Winter = Jan. to Mar.; Summer = Jul. to Oct.

[a]. duration calculated from 1990 to 1997.

Table 7. Stream water temperature characteristics in selected Atlantic salmon rivers in the Maritime Provinces. Temperatures in deg. C.

River	Maximum daily mean	Maximum recorded	No of days above 23 °C
Catamaran Brook (NB)	20.8 (Jul 18)	24.5 (Jul 17)	4
LSW Miramichi R. (NB)	26.1 (Jul 18)	29.9 (Jul 31)	62
SW Mira. R. at Sister's Bk (NB)	23.4 (Jul 17)	27.1 (Jul 17)	29
SW Mira. R. at Millerton (NB)	26.4 (Jul 19)	27.1 (Jul 19)	59
SW Miramichi R. at Wade (NB)	25.9 (Jul 18)	28.7 (Jul 17)	60
NW Mira. R. at Cassilis (NB)	26.5 (Jul 18)	27.5 (Jul 18)	61
SW Miramichi R. at Nelson (NB)	23.1 (Jul 01)	25.9 (Jul 17)	18
Tomogonops River (NB)	24.2 (Jul 18)	29.3 (Jul 17)	51
Nashwaak River (NB)	26.4 (Jul 18)	29.4 (Jul 17)	67
Tobique R. at Arthurette (NB)	26.5 (Jul 18)	30.6 (Jul 18)	61
Mactaquac Fishway (NB)	23.2 (Aug 01)	23.7 (Jul 30)	13
Kennebecasis River (NB)	22.0 (Jul 18)	24.0 (Jul 17)	3
Morell River at Grants (PEI)	21.1 (Jul 17)	23.4 (Jul 17)	2
Morell River at McKenna (PEI)	23.6 (Jul 18)	26.2 (Jul 17)	38
Morell River at St. Patrick (PEI)	21.3 (Jul 31)	25.9 (Jun 13)	12

Table 8. Monthly water temperatures at Catamaran Brook Middle Reach (located in central New Brunswick, a part of the Miramichi River Basin). All temperatures are expressed in °C.

Month	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**
1991	n/a	7.76	12.45 *	14.66	15.07 *	n/a	n/a
1992	n/a	8.11 *	11.55	12.15	12.86	11.56	5.58
1993	0.35	5.80	10.52	13.39	14.79	10.69	4.49
1994	0.75	4.98	12.41	16.58	15.22	10.26	5.55
1995	0.99	5.89	13.52	16.24	15.26	9.88	7.18
1996	0.72	5.41	13.63	14.29	15.22	11.51	6.01
1997	0.38	3.84	11.48	13.91	13.72	11.04	4.79
1998	2.55	8.91	11.40	14.70	14.27	11.31	6.51
1999	1.60	9.27	15.22	17.23	16.52	14.16	5.84
Mthly Mean	0.64	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).

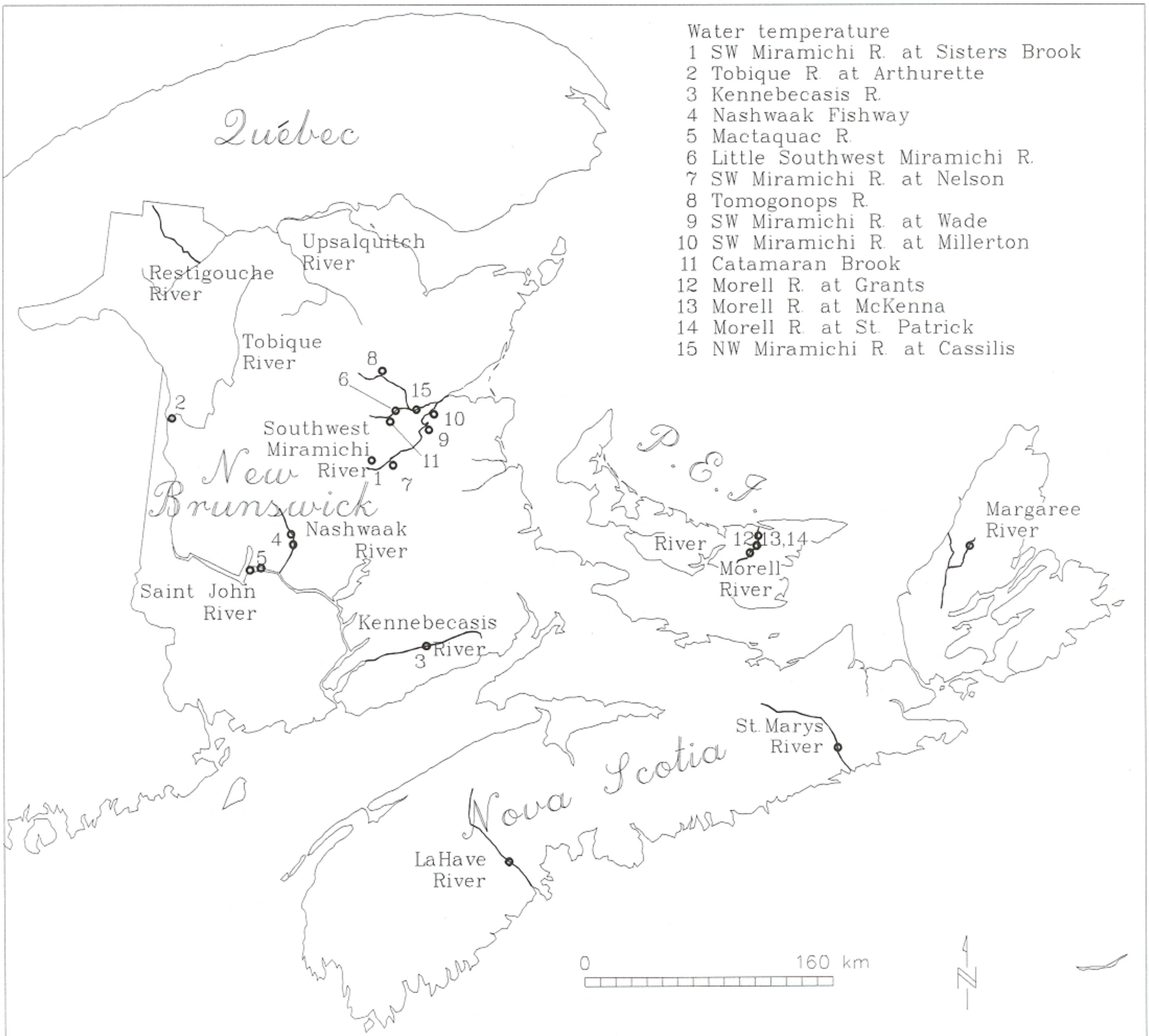

Figure 1. Location of water temperature stations on selected Atlantic salmon rivers in the Maritime Provinces.

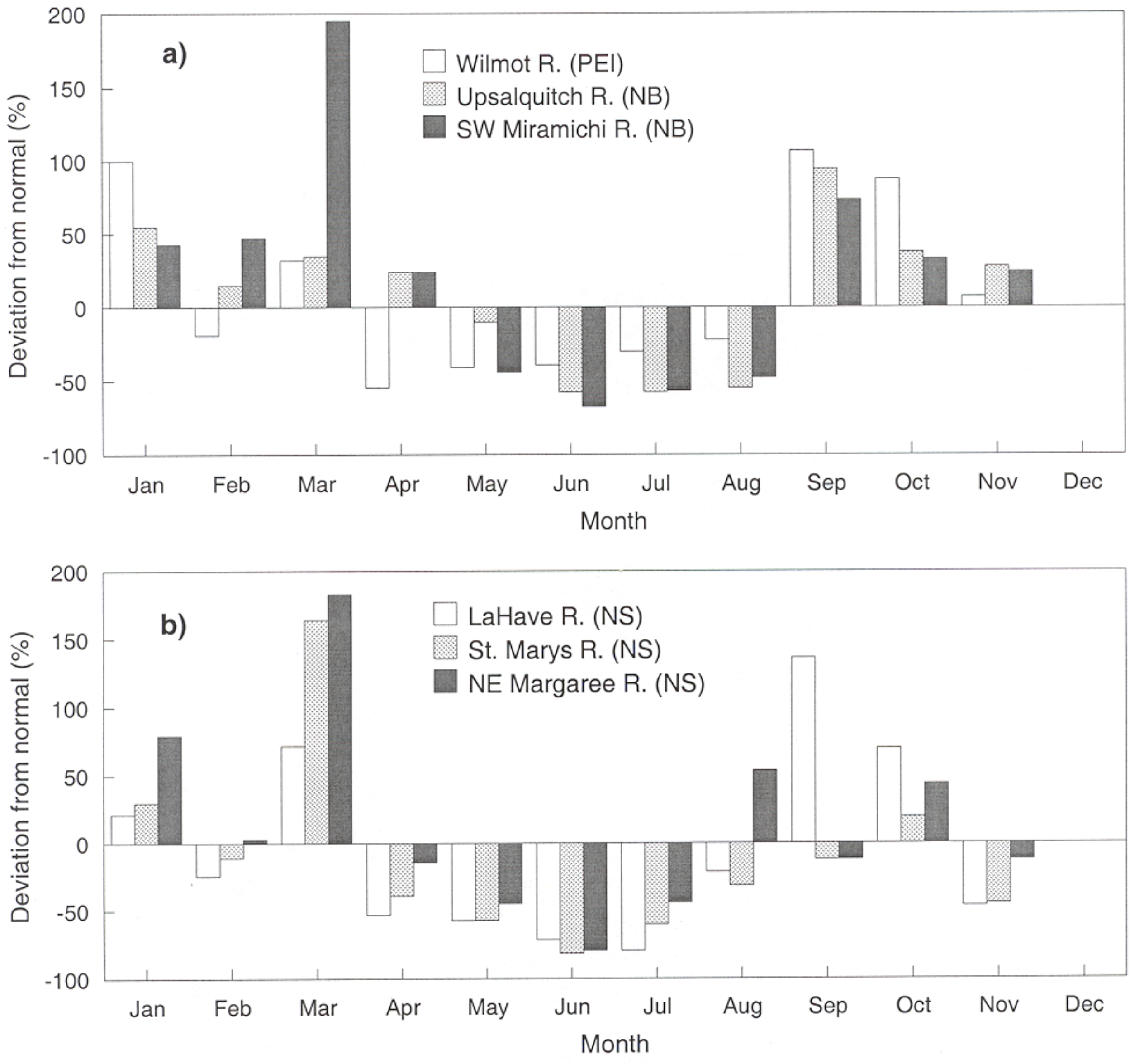

Figure 2. Deviation from normal monthly discharge in 1999 (in percentage, %) for studied rivers in the Maritime provinces.

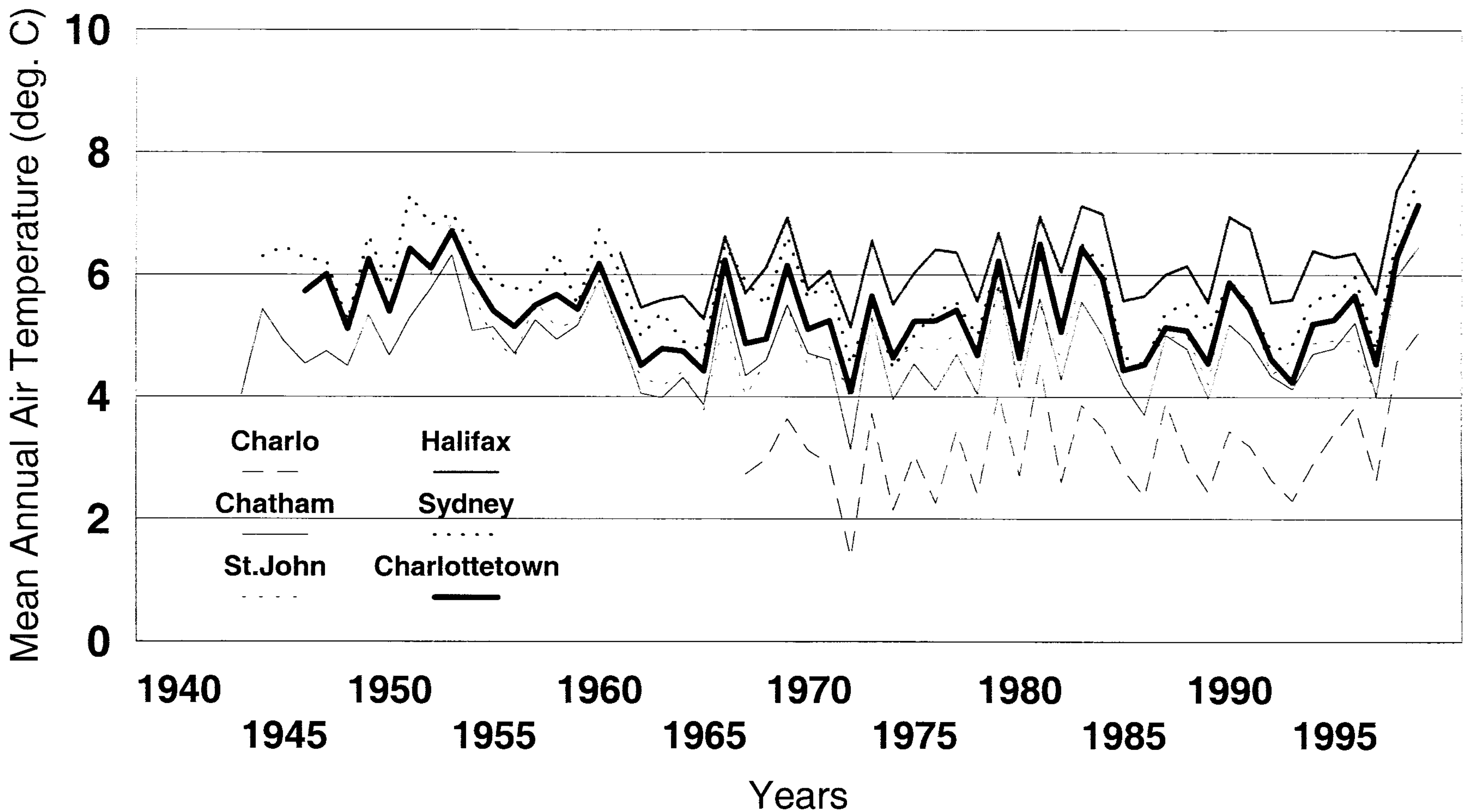

Figure 3. Long-term annual air temperature at different sites within the Maritime Provinces

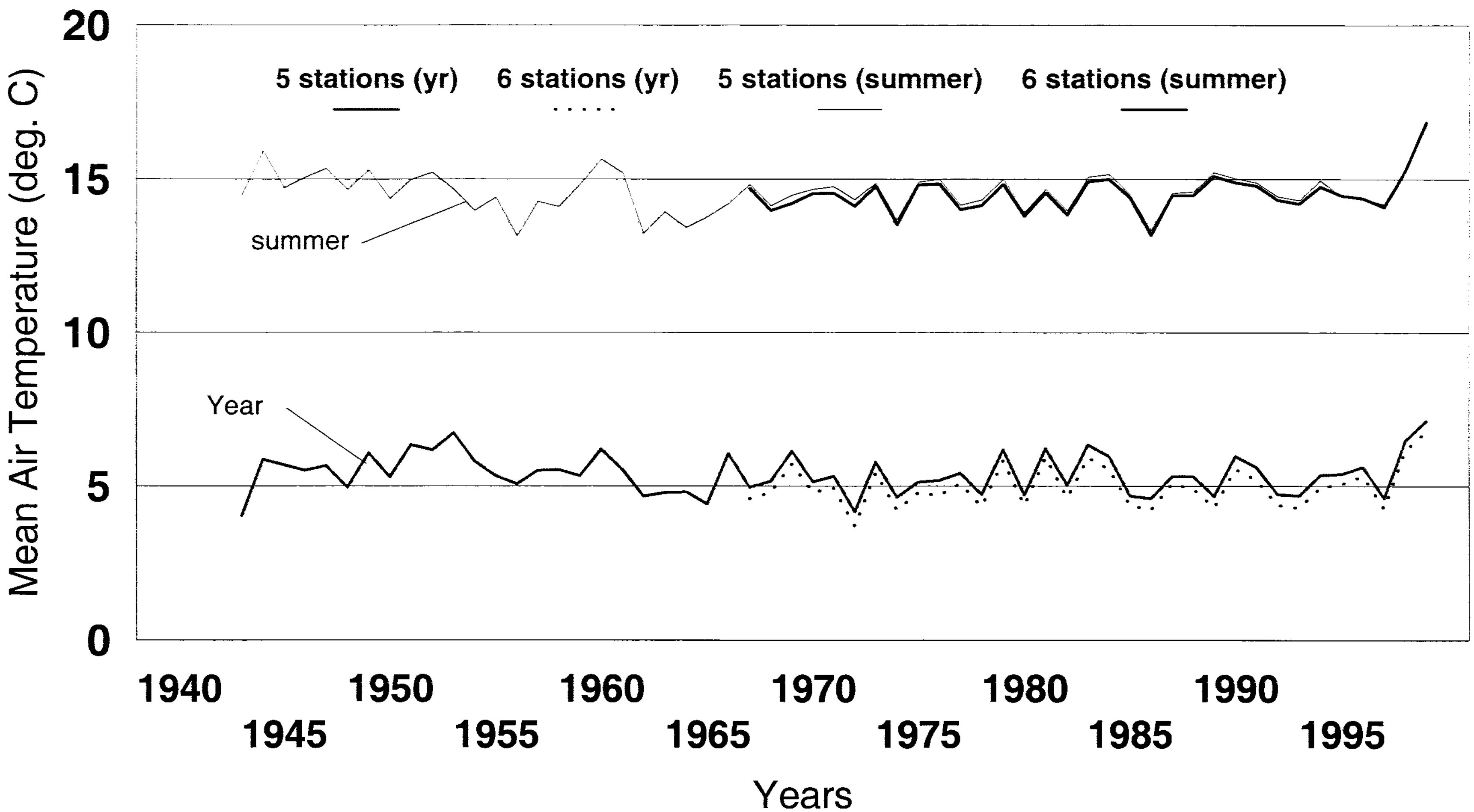

Figure 4. Long-term average air temperature within the Maritime Province in summer and on a annual basis. 5 or 6 stations were considered depending on the analysis.

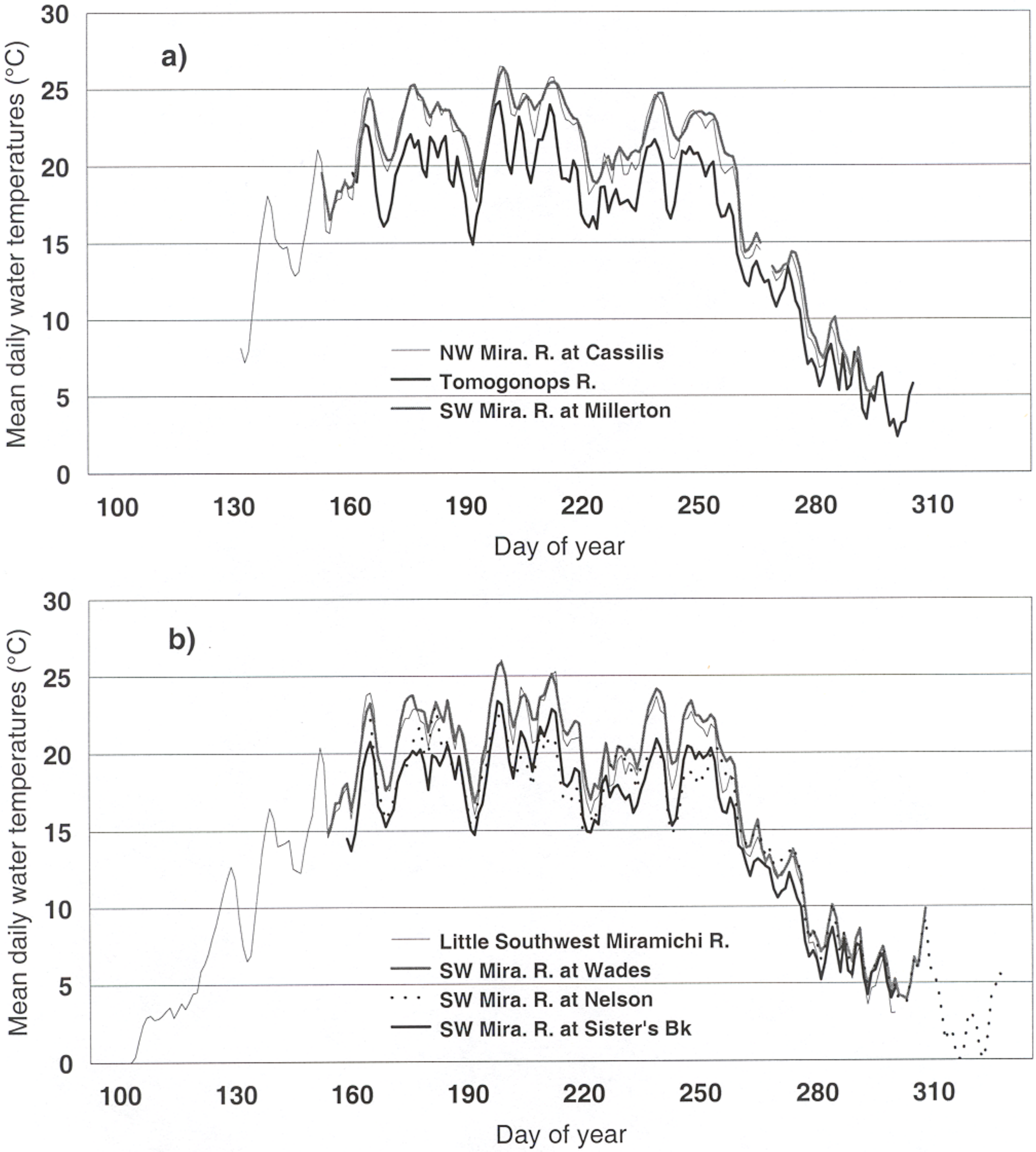

Figure 5. River water temperatures (°C) in the Miramichi River in 1999 (day 100 = Apr. 10).

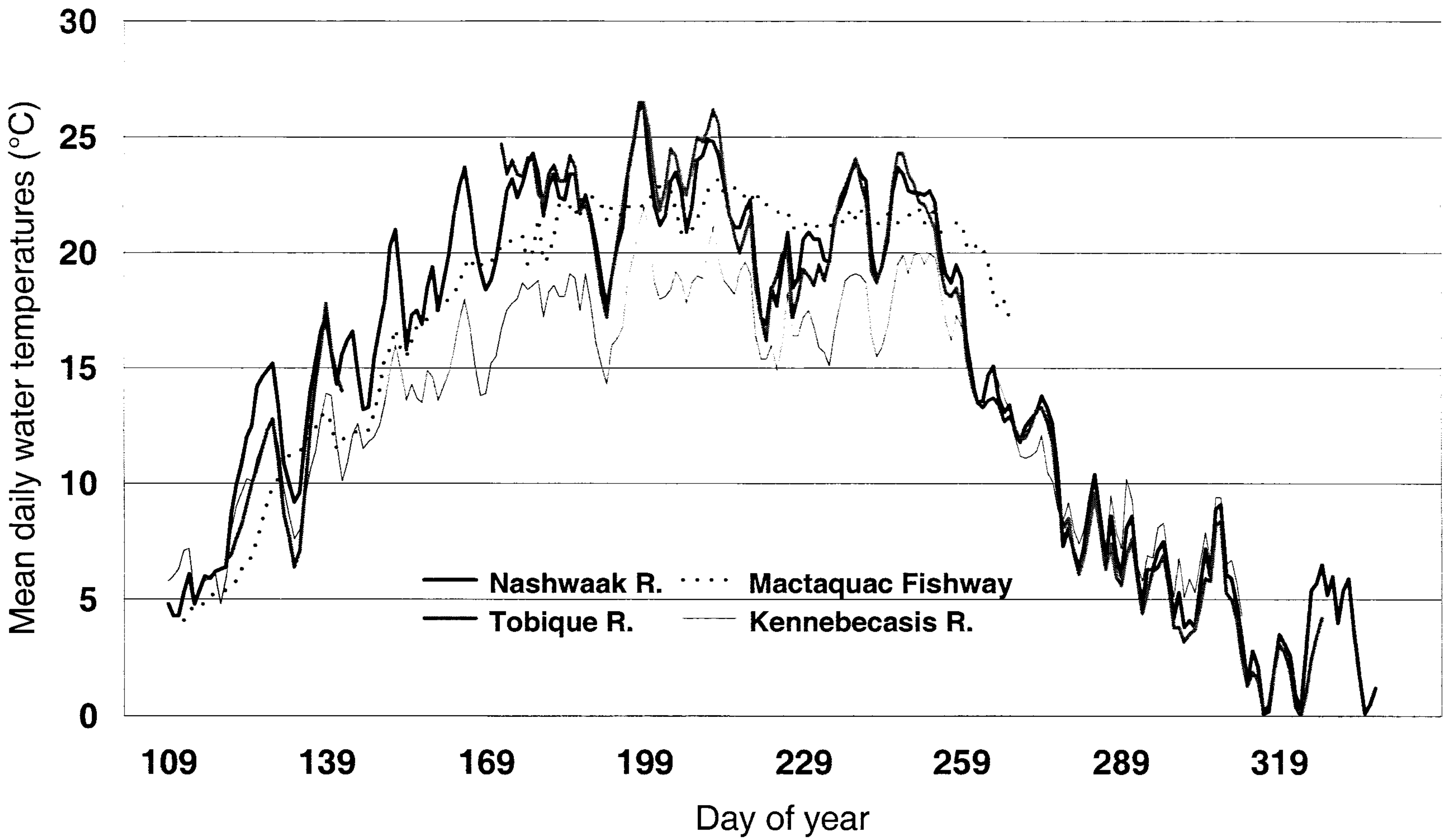

Figure 6. River water temperatures (°C) for different location in NB in 1999 (day 109 = Apr 19).

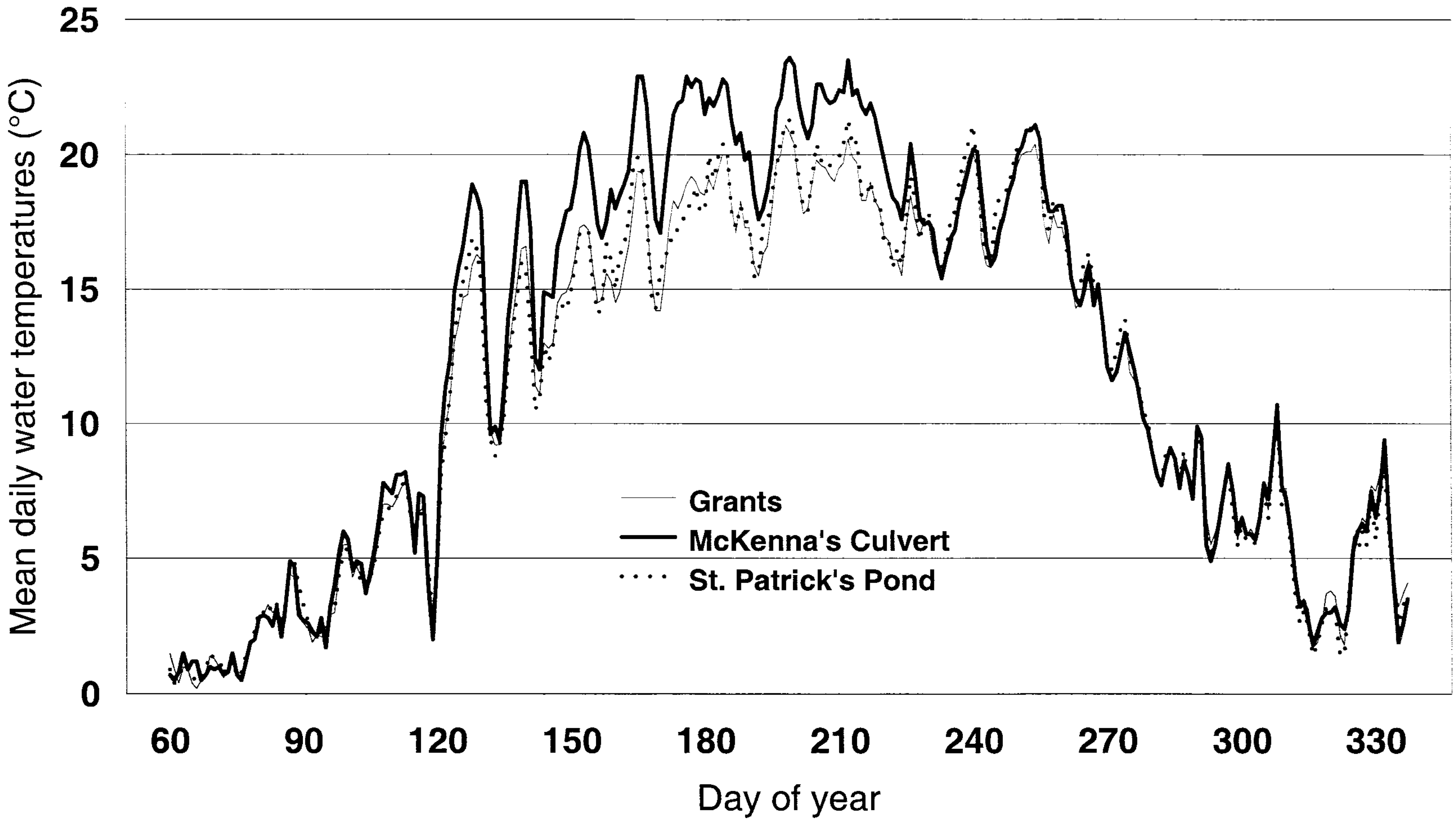

Figure 7. River water temperatures (°C) in selected rivers in PEI in 1999 (day 60 = Mar. 1).

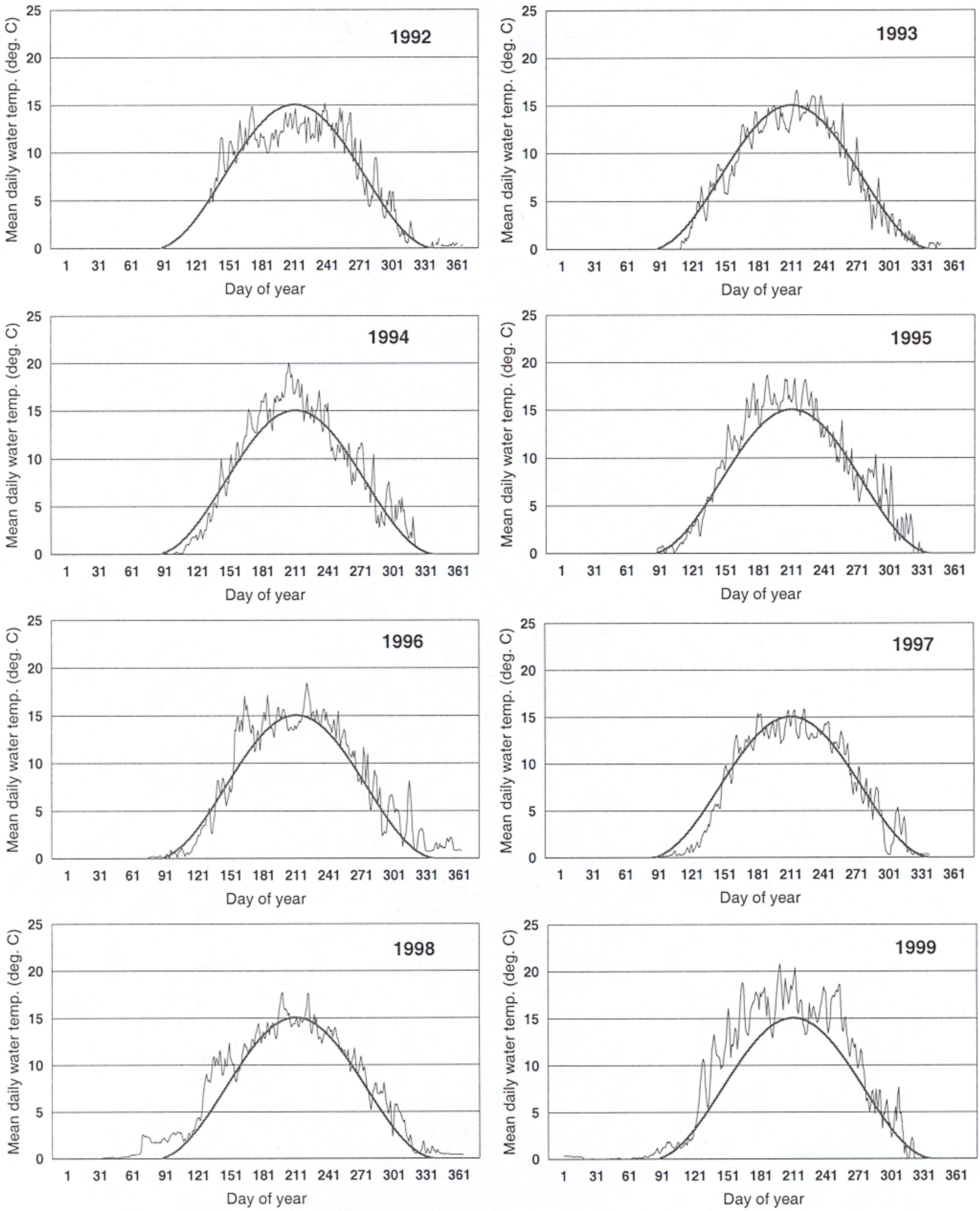

Figure 8. Stream water temperature at Catamaran Brook (Middle Reach) from 1992 to 1999; Fourier series represents long-term temperatures.