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Hydrometeorological conditions for Atlantic salmon rivers in the Maritime provinces

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems 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.

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ABSTRACT

This study provides historical information on hydrometeorological conditions and trends for Atlantic salmon (*Salmo salar*) rivers within the Maritime provinces. In total, 8 rivers were studied and at each river, discharge characteristics (high flow, low flow and streamflow timing) were presented as well as long-term trends in the discharge time series. Long-term mean air temperatures and precipitations were presented at 8 meteorological stations close to the studied rivers as well as annual and summer air temperature trends. A spatial variability in mean annual air temperature exists within the Maritime provinces and air temperatures varied between 4.8 °C (Bathurst) and 6.6 °C (Halifax). This gradient in mean annual air temperature has an influence on river discharge and river temperature. Northern rivers experienced lower winter flows followed by a pronounced snowmelt runoff in the spring. The southern rivers experienced more mixed snow/rainfall dominated winters with correspondingly higher winter flows. The spring high flow period was also different among rivers where northern rivers tended to reach their high flow later (May) than southern rivers (April). The summer low flow period generally extended between the end of July to early September. Significant floods and low flow events have been observed within the study area over the past 20 years. For instance, many rivers experienced close to a 100-year flood event (Nashwaak River 2010; St. Marys River 2003; LaHave River 2003; Northeast Margaree River 2010). Similarly, 100-year low flow events were observed in Miramichi (2002), Nashwaak (2001) and LaHave (2016), rivers. When looking at low flows across the region, Nova Scotia (NS) rivers are experiencing the most severe summer low flows (100-year events). In fact, the St. Marys and LaHave rivers can reach less than 1% of the mean annual flow. Timing of high flow events differed among provinces as well; the majority of high flow events in New Brunswick (NB) rivers occurred near the spring freshet whereas high flow events in NS rivers were spread out throughout the year. High flow events at the Prince Edward Island (PEI) river (Wilmot River) were generally grouped, similar to NB rivers, but tended to occur earlier in the year. As in previous studies, river temperature across the region show some variability (both at the spatial and temporal scales). The Nashwaak and Little Southwest Miramichi rivers showed a significant number of days where daily Tmax was greater than 23 °C during the summer period (29 and 32 days on average per year, respectively). In contrast the Restigouche River (Butters Island) showed less that 10 days on average per year. When looking at the mean annual air temperature trends, most stations showed a significant increase in the Maritime provinces. The increase in mean annual air temperature was between 1.2 °C (Charlottetown) and 2.0 °C (Bathurst) over the past 100 years. Increases in summer air temperatures were also significant at most sites over the past 100 years, but slightly lower (1-1.7 °C). Results also showed a significant increase in precipitation at 50% of the sites, with increases between 10-31 mm per decade. The high flow timing was significantly earlier at 75% (6/8) of the rivers representing a 2-3 days change per decade. Most trends in the magnitude of high flow were not significant. In fact, only one station showed a significant decrease in flow (Nashwaak River). The timing of summer low flow only showed one significant decrease in the timing (Wilmot River; 9 days per decade). The magnitude of low flow did not show any significant trends. Some rivers showed a significant increase in summer (July and August) water temperatures over the past 25 years (Little Southwest Miramichi River, Kedgwick River and Restigouche River at Butters Island). The increases were in the order of 0.8 °C to 2.2 °C per decade.

INTRODUCTION

An understanding of hydrological conditions is important in the management of fisheries and aquatic resources as well as in the management of freshwater habitats. Some events such as streamflow availability and variability can affect stream biota at different life stages as well as during different seasons of the year. For example, salmonids can be affected by extreme events such as high flow events (Elwood and Waters 1969; Erman et al. 1988) or during low flow conditions; the latter is often associated with high river water temperatures (Lund et al. 2002; Edwards et al. 1979). In order to increase our knowledge of environmental conditions of Atlantic salmon rivers for the purpose of assessing Atlantic salmon stocks and for the management of freshwater ecosystems, we need to study the stream hydrology and river temperatures for these rivers and associated extreme events (high and low flows) and corresponding trends.

The objective of the present study is to analyze hydrometeorological data for important Atlantic salmon rivers to specifically address the pre-COSEWIC assessment of Atlantic salmon within the Maritime provinces. The specific objectives are: a) to provide an overview of the precipitation and air temperatures at 8 meteorological stations and flow conditions for 8 rivers, b) to analyze high and low flow conditions at these sites, c) to determine the frequency of these high and low flow events, d) to study river temperatures at selected sites and e) to identify abnormal events and long-term trends in time series.

METHODS

Historical data on air temperature and precipitation were obtained from Environment Canada's data base of Adjusted and Homogenized Canadian Climate Data (AHCCD), and Air temperature and precipitation data were obtained from the Environment Canada Historical Data website in order to complete the data series up to 2020. Air temperature and precipitation data were obtained for 8 stations within the Maritime provinces (Table 1). Series lengths for air temperature ranged between 93 years and 145 years. For all stations, precipitation data starts on the same year or a few years after the start of air temperature data (*e.g.* around 1870), except for Bathurst, where precipitation data starts in 1884 (*i.e.*, 37 years before air temperature data; 1922). Figure 1 shows the locations of the selected meteorological stations within the Maritime provinces.

Daily mean discharge data from selected rivers were used to calculate high and low flow characteristics for different recurrence intervals (T-year events). Annual high flows were fitted to the Generalized Extreme Value (GEV) probability distribution (Kite 1978) and a frequency analysis was carried out to estimate the T-year high flow events for each river. In contrast, the 3-parameter Weibull (or type III extremal) probability distribution was used to estimate the low flow frequency events using daily minimum discharge on an annual basis (Kite 1978).

A peaks over threshold approach was used to identify timing of high flow events. This approach consists of analyzing all flows above a threshold or truncation level, Q_{TL}. Here, the truncation level was chosen to correspond to 1.5 high flow events per year, on average (i.e., the n largest peak flows and their timing are identified, where n = 1.5 x number of years).

Water temperatures were also analyzed at a few sites. Here a focus was put on summer water temperatures (July and August) as these two months account for the highest temperatures of the year and potentially the more stressful months for Atlantic salmon. Water temperature characteristics for both the Miramichi and Restigouche rivers have been described previously (Caissie et al. 2013), and the contrast between these two systems has been studied. The present study will focus on updating threshold values (*e.g.*, number of days where daily Tmax exceeded 23 °C) and on trends analyses at selected sites. For this analysis, 5 water temperature sites were used, namely the Little Southwest Miramichi River (above Catamaran Brook and at the Oxbow site), the Kedgwick River, the Restigouche River (at Butters Island) and the Northwest Upsalquitch River.

Trends in meteorological data were analyzed using linear regressions. For air temperature, annual temperatures as well as summer (July and August) were analyzed. For precipitation, total annual precipitations were used in the analysis. For water temperature, the summer (July and August) temperatures were used.

Following the frequency analysis for discharge, long-term trends were investigated for each river using the mean annual flow, peak discharge (daily) and low flows. Peak flows and low flows were also investigated both in their timing or occurrence (day of year) and magnitude (discharge, m^3/s). This analysis consisted of calculating a 30-day running mean where spring peak flows were identified as well as summer low flows. Linear regressions were then used to identify trends as well as their significance. For the high flow period, the 30-day period with the highest average between day 30 (*i.e.,* the mean between January 1 to January 30) and day 212 (*i.e.*, the mean between July 2 to July 31) was identified. The high flow period was then refined as being between day 40 (February 9) and day 160 (June 9). Years where the high flows were outside of the defined high flow period (day 40 to day 160, above) were excluded from the linear regression analysis. For low flows, the 30-day period with the lowest average flow between day 120 (*i.e.*, April 30 with the mean between April 1 to April 30) and day 365 (*i.e.*, which includes the 30-day period between December 2 to December 31) was identified. The low flow period was then refined as being between day 140 (May 20) and day 365 (December 31). For years where the low flows were outside of the above defined low flow period (day 140 to day 365), these low flow data were excluded from the linear regression analysis.

RESULTS AND DISCUSSION

STUDY AREA

The study area consists of 8 rivers within the Gulf Region (Figure 1). Four of the 8 rivers are in New Brunswick / NB (Restigouche, Northwest Miramichi, Southwest Miramichi and Nashwaak rivers), 3 are in Nova Scotia / NS (St. Marys, LaHave and Northeast Margaree rivers) and 1, the Wilmot River, is in Prince Edward Island / PEI. Daily average discharge data were gathered from the Historical Hydrometric Data Search website. The number of years of data ranged between 48 (Wilmot River) and 103 (St. Marys and LaHave rivers; Table 2).

Table 2 also shows selected stations' characteristics. The drainage basins of the studied rivers ranged between 45.4 km^2 (Wilmot River) and 5 050 km^2 (Southwest Miramichi River). The mean annual flow (MAF), which is a function of the drainage area, varied between 0.95 m^3/s for Wilmot River and 121 m^3/s for Southwest Miramichi River. The mean annual runoffs, *i.e.*, the MAF expressed in unit discharge (mm; *i.e.,* discharge per drainage area), were used to compare discharges between basins of different sizes. The river with the lowest runoff was LaHave River with a runoff of 376 mm whereas the river with the highest runoff was the Northeast Margaree River with a runoff of 1460 mm.

AIR TEMPERATURE AND PRECIPITATION

Table 3 presents the results for air temperature climate normals (1981-2010) and precipitation at the studied meteorological stations across the Maritime provinces. The coldest month of the year is January with mean monthly air temperatures between -10.8 °C (Bathurst; Miramichi) and -5.4 °C (Sydney). The warmest month of the year throughout the Maritime provinces is July with mean monthly air temperatures between 17.1 °C (Saint John) and 19.4 °C (Fredericton). Although July is the warmest month, the month of August closely follows July with a mean monthly air temperature difference less than 1 °C. Figure 2 shows the changes in monthly mean air temperatures throughout the year. Winter air temperatures were observed to be milder in NS compared to NB and PEI. Air temperatures are generally positive for 8 months of the year, between April and November. The summer high air temperature months are July and August, and these two months showed consistent temperatures within the region with the exception of Saint John, which showed slightly lower temperatures. Table 3 also reports on the mean value of daily minimum air temperatures as well as the mean value of the daily maximum air temperatures. January showed the lowest value for the mean daily minimum (-9.6 °C to -16.2 °C) whereas July showed the highest mean daily maximum air temperatures (22.6 °C to 25.4 °C; Table 3). The mean annual air temperature within the Maritime provinces was between 4.8 °C (Bathurst) and 6.6 °C (Halifax). The study region generally observed extreme temperatures between -38.9 °C in winter to 38.9 °C in summer with slightly milder air temperatures in southern NB, NS and PEI.

The monthly precipitation is evenly distributed throughout the year at approximately 100 mm per month depending on the total annual precipitation (Table 3). There is a slight gradient in precipitation within the Maritime provinces with lower amounts of precipitation in northern NB (Bathurst, 1110 mm; Miramichi, 1072 mm and Fredericton, 1095 mm) and higher amounts in NS, particularly in Halifax (1396 mm) and Sydney (1517 mm; Table 3; Figure 3). Southern NB showed annual precipitation over 1200 mm (*e.g.*, Moncton, 1200 mm and Saint John, 1296 mm) whereas PEI showed a value of 1158 mm for Charlottetown.

FLOW CHARACTERISTICS

Following the analysis of air temperature and precipitation, discharge was analyzed for Atlantic salmon rivers throughout the Maritime provinces. Table 4 shows both monthly and annual discharge at the studied stations as well as unit monthly flows (*i.e.*, discharge per unit area, expressed in liters per second per square kilometer, L/s per km^2). Monthly flows varied between high values in the spring (mainly in April and May) to low values in late summer (mainly in August and September). Some stations in NB (*i.e.*, Restigouche River, Southwest Miramichi River and Northwest Miramichi River) also showed low winter monthly flows, particularly in February. The mean annual flow varied between 0.952 m^3/s (Wilmot River, PEI) to 121 m^3/s (Southwest Miramichi River) and reflects the size of the drainage basins. Discharge per unit area also showed a similar pattern as above; however, a better comparison among basins can be carried out with discharge per unit area. For instance, low winter flows were observed in February with values of 6.1 L/s per km^2 (Restigouche River) to 10.9 L/s per km^2 (Southwest Miramichi River). Winter flows in NS and PEI were much higher with values over 22-30 L/s per km^2 (Table 4). Spring high flows were generally observed in April and May and the station with the highest flow month was Northeast Margaree River with a discharge of 112.5 L/s per km^2 (May; Table 4). Low summer flow months were August and September with flows of 6.8 to 11.4 L/s per km^2, with the exception of the Northeast Margaree River which showed much higher flows (18.1 L/s per km^2 July and 20.1 L/s per km^2 August). Figure 4 shows the discharge per unit area for all studied stations and for each month. This figure clearly shows the differences in winter monthly flows in NB vs. NS and PEI. NS rivers have much higher flows in winter (20-40 L/s per km^2). Spring flows were similar among rivers; however some rivers showed highest flow in April (NS rivers) while others showed highest flow in May (Restigouche River and Northeast Margaree River). The rivers in central NB (Southwest Miramichi and Northwest Miramichi rivers) showed discharge that were similar between April and May.

To more closely study the flow regime of Atlantic salmon rivers, daily discharges per unit area were calculated (Figure 5). Results showed that rivers in NB experienced more severe winter low flows than other rivers in the Maritime provinces. NS rivers show higher autumn and winter flows. The Northeast Margaree River showed among the highest flows throughout the year, including summer. The high and low flow period (timing) varied significantly throughout the Maritime provinces. Based on a 30-day running mean, the high flow period arrived the earliest for Wilmot River (day 100; April 10) followed by LaHave River (day 102; April 12) and St. Marys River (day 105; April 15). Nashwaak, Southwest and Northwest Miramichi rivers showed timing of high flow on day 115 (April 25), 119 (April 29) and 122 (May 2) respectively. The Restigouche and Northeast Margaree rivers showed the latest high flow season with both their high flow timing on day 127 (May 7). Both these rivers also showed highest unit discharge with values exceeding 100 L/s per km^2 on a daily basis. For the low flow season, two rivers showed more severe winter low flows than summer low flows (*i.e.*, Restigouche and Northwest Miramichi rivers). In fact, the Restigouche and Northwest Miramichi rivers showed winter low flows occurring on day 55 and 54 (February 24 and 23), respectively. The summer low flow period extended between day 210 (July 29) and day 253 (September 10) depending on the river. The rivers with the earliest summer low flows were St. Marys River (day 210; July 29) and the Northeast Margaree River (day 212; July 31). The summer low flow for the St. Marys River were approximately 9.6 L/s per km^2 whereas the low flow for the Northeast Margaree was at 16.2 L/s per km^2 on a daily basis. In fact, the Northeast Margaree River showed the least severe low flows among all stations (Figure 5). Other rivers showed similar low flow timing between late August and early September: Wilmot River (day 235; August 23), Nashwaak River (day 243; August 31), LaHave River (day 243; August 31), Southwest Miramichi River (day 249; September 6), Restigouche River (day 250, September 7), and Northwest Miramichi River (day 253; September 10). Notably, the summer low flows values were similar to that of the winter low flows (see above) and between 9 L/s per km^2 and 10 L/s per km^2 on a daily basis; however, LaHave River experienced slightly lower low flows with values of 6.4 L/s per km^2.

Following the analysis of flow regimes which define the period of high and low flow periods throughout the year, a high and low flow frequency analysis was carried out. The high and low flow frequency analysis better quantifies extreme events which can potentially have an impact on fish habitat and aquatic resources. For the high flow frequency, the generalized extreme value (GEV) probability distribution was used to fit the data. For the low flow frequency analysis the Weibull 3-parameter probability distribution was used. Results are shown in Table 5 for recurrence between 2 and 100 years. Both high and low flow magnitudes are reflective of the drainage basin sizes. High flow values varied between 11.4 m^3/s (Wilmot River, T = 2 years) and 2018 m^3/s (Southwest Miramichi River, T = 100 years). Low flows varied between 0.075 m^3/s (LaHave River, T = 100 years) and 18.6 m^3/s (Southwest Miramichi River, T = 2 years). Figure 6 shows the fitted flood frequency distributions and the year of the corresponding highest floods (highest 5 years) for all studied rivers. For the Restigouche River, recent high return floods (*i.e.*, close to a 100-year event) were observed in 2008 (1220 m^3/s), 2018 (985 m^3/s) and 2017 (908 m^3/s; Figure 6a). The 2018 and 2017 floods are higher than a 10-year event, and the 2008 flood is higher than a 50-year flood. For the Southwest Miramichi River, the 2018 (1660 m^3/s) and 2010 (1660 m^3/s) floods were events that represented close to a 25-year flood event (Figure 6b). The Northwest Miramichi River showed recent floods in 2010 (474 m^3/s) and 2017 (431 m^3/s; Figure 6c). Similar to the Southwest Miramichi River, these floods represented close to a 25-year flood event. The Nashwaak River showed the highest flood event in 2010 (1150 m^3/s) and 2015 (774 m^3/s; Figure 6d). The 2015 flood represented close to a 25-year flood events whereas the 2010 flood event exceeded a 100-year event (Table 5). Notably, other years in NB where high return floods were observed included 1970, 1973, 1979 and 1994. For St. Marys River, the highest flood was recorded in 2003 (976 m^3/s;

Figure 6e) and represented a 100-year event. LaHave River also experienced high return flood events in 2003 (663 m^3/s; Figure 6f) as well as in 2010 (460 m^3/s). The 2010 flood represented a 20-year flood event whereas the 2003 event represented close to a 100-year event. The Northeast Margaree River experienced a recent high flow event in 2010 (383 m^3/s; Figure 6g), and this flood represented close to a 100-year event. The five largest floods in Wilmot River were after 2005 (Figure 6h) with the highest flood occurring in 2012 (35.5 m^3/s) followed by 2005 (32.3 m^3/s). The 2012 flood event represented a 50-year event.

When looking at low flow events across the Maritime provinces, the Restigouche River does not show any recent low flow events in the past 20 years (Figure 7a). The most recent low flow events were observed in 1993 and 1998. For the Southwest Miramichi River, low flow events were observed in 2002 (10.6 m^3/s), 2017 (12.1 m^3/s) and 2001 (12.3 m^3/s; Figure 7b). The 2002 low flow event was a 100-year event whereas the other low flow events were closer to a 20-year event. For the Northwest Miramichi River, the most recent low flow event occurred in 2018 (1.92 m^3/s), and this event represented close to a 10-year event (Figure 7c). The Nashwaak River experienced low flow events in 2001 (2.16 m^3/s), 2017 (2.26 m^3/s) and 2002 (2.33 m^3/s; Figure 7d). The 2001 event represented a low flow event exceeding the 100-year recurrence interval, whereas the 2017 and 2020 represented low flow events close to a 50-year event. The St. Marys River experienced a recent low flow event in 2001 (0.308 m^3/s), which is close to a 20-year low flow event (Figure 7e). LaHave River experienced its lowest low flow event in 2016 (0.037 m^3/s), and this event represents a 100-year event (Figure 7f). The Northeast Margaree River did not experience among the lowest flow events in the past 20 years (Figure 7g). Among the five lowest low flow events, they were observed prior to 1998. The Wilmot River experienced a low flow event in 2002 (0.232 m^3/s), and this low flow is close to 5-year event.

The last columns of Table 5 present the high and low flow event in unit discharge (discharge per drainage area, expressed in L/s per km^2). Within the Maritime provinces, the highest floods per drainage area are observed in the Northeast Margaree River (1077 L/s per km^2; T = 100 years), followed by the Wilmot, Nashwaak and St. Marys rivers. For the Northeast Margaree River, even the 2-year flood was the highest in the region (452 L/s per km^2; T = 2 years). The largest rivers (Restigouche and Southwest Miramichi rivers) showed the lowest discharge per unit area (400-412 L/s per km^2; T = 100 years), most likely due to the large size of these basins. When looking at low flow events, the Northeast Margaree River showed the highest low flows (3.7 L/s per km^2; T = 100 years; Table 5), followed by the Wilmot River (3.4 L/s per km^2) and Southwest Miramichi River (2.1 L/s per km^2). As noted previously, the Northeast Margaree River has the highest flows per drainage area throughout the year, including the low flow period. The relatively high flows (during low flow periods) for the Wilmot River is partially due to the fact that this river has a lot of groundwater / baseflow contribution, which is typical of PEI rivers. The Southwest Miramichi River is the largest river in the study area, and thus has a good baseflow component, as most larger rivers do. The most severe low flows were observed in NS at LaHave and St. Marys rivers with 100-year low flow events of 0.06 L/s per km^2 and 0.14 L/s per km^2 respectively. It is clear that these NS rivers experience much lower flows than other rivers in the Maritime provinces. Low flows as a percentage of the mean annual flow (MAF; Table 2) are presented for the 2-year and the 100-year low flows (Figure 8). This figure shows that most 2-year low flows are above the 10% MAF with the exception of St. Marys River, which is only 3% MAF. This means that this river reaches low flows less than 10% MAF on average every other year. As for the 100-year low flows, most rivers are within 6%-9% MAF; however, both St. Marys and LaHave rivers are less than 1% MAF. Such results show the severity of low flows for some NS rivers, which can potentially impact fish habitat and summer water temperatures. In the case of Wilmot River, it is clear that groundwater is a significant contributor to baseflow as the 2-year and the 100-year low flows only represented 33% and 16% of the MAF, respectively.

Figure 9 shows the timing (day of year) and magnitude of the highest peak flows on record (*i.e.*, extreme events). The year was divided in three periods. The first is winter high flows, which occur between day 1 (January 1) and day 74 (March 15). The second period is between day 75 and 304 (October 31) which covers spring, summer and early autumn flows. The third period is between day 305 and 365 (December 31) and covers late autumn flows.

Timing of high flows was somewhat similar for rivers in New Brunswick (Figure 9, a to d). Most high flow events occurred between days 75 and 304 (78% for Nashwaak River and 95% for Restigouche River). Few high flow events occurred during winter for these rivers (between 0 and 7% for the Restigouche and Nashwaak rivers respectively). Slightly more high flow events occurred in late autumn for rivers in New Brunswick with 5% to 15% of events occurring during this period. Rivers in NS (Figure 9, e to g) showed more variability in timing of high flow events with 18% (Northeast Margaree River) to 28% (St. Marys and LaHave rivers) of high flow events occurring in the winter period. High flows in the spring, summer and early autumn accounted for 44% (St. Marys and LaHave rivers) to 63% (Northeast Margaree River) of events. Between 19% (Northeast Margaree River) and 28% (St. Marys and LaHave rivers) of high flow events occurred in late autumn. In the case of the Wilmot River (PEI), 36% of high flow events occurred in the winter period, 57% in the spring, summer and early autumn period and 7% in the late autumn period (Figure 9h).

High flow events were more tightly grouped for rivers in NB and PEI, where the standard deviations were between 59 days (Restigouche River) and 90 days (Nashwaak River). NS rivers showed high flow events that were more spread out throughout the year. Here, standard deviations ranged between 106 days (Northeast Margaree River) to 125 days (St. Marys River). Though the Wilmot River had similar standard deviations as NB rivers, the timing was different, where NB rivers showed fewer winter high flows than late autumn high flows, the Wilmot River showed more winter high flows than late autumn high flows.

WATER TEMPERATURES

Water temperature characteristics for the Miramichi and Restigouche rivers have been described previously (Caissie et al. 2013). In this previous study both the annual and diel cycles have been described, as well as important spatial differences in river temperatures within each studied watersheds. One important thing to note from this past study was that river systems can have marked thermal differences. Notably the Miramichi River system has higher mean river temperatures than the Restigouche River. Similarly important, the spatial differences can exist within each river system, mainly driven by the size of the watershed, the amount of shade or overhanging vegetation and groundwater inputs. The objective of the present study is not to analyze previously described thermal regimes and river temperature variability, but rather to update a few important components. A component of the river temperature regime which is important for salmon rivers is the number of days per year where the maximum daily water temperature exceeds 23 °C. These high temperature events can represent periods of stressful days for both adult and juvenile Atlantic salmon. Figure 10 presents the number of days each year between 1992 and 2020 for 4 selected sites within the Maritime provinces. For example, the Little Southwest Miramichi River (missing data in 1994) showed on average 32 days per year of daily Tmax exceeding 23 °C. The highest value years were 1999 (62 days), 2018 (57 days), 2001 (52 days) and 2002 (52 days; Figure 10a). The Restigouche River (Butters Island) showed a mean value of 10 days per year for data between 2003 and 2020 (missing data in 2007), and a maximum occurrence of 39 days in 2018 followed by 36 days on 2020 (Figure 10b). For the Northwest Upsalquitch River, the value was 9 days per year on average (data between 2003 and 2020, with missing values in 2007). The maximum number of days was observed in 2020 with 39 days (Figure 10c). The Nashwaak River showed a mean value of

29 days per year (data between 1995 and 2019; missing values in 2011). The maximum occurrence of daily Tmax exceeding 23 °C was observed in 1999 (67 days) and 1995 (55 days; Figure 10d). These results show that the Nashwaak River shows a similar regime than the Little Southwest Miramichi River whereas sites in the Restigouche River shows slightly colder summer conditions.

HYDROMETEOROLOGICAL TRENDS

Historical mean annual and mean summer (July and August) air temperatures were analyzed using linear regressions. Figure 11 shows mean annual air temperatures over several decades (approximately 90 to 140 years) as well as the regression line. An increase in air temperature was observed at each weather station. Air temperatures in NB increased, on average over 100 years, between 1.4 °C (Moncton, Figure 11d; Saint John, Figure 11e) and 2.0 °C (Bathurst, Figure 11 a). For weather stations in NS, mean annual air temperature increased by 1.4 °C (Sydney, Figure 11g) and by 1.7 °C (Halifax, Figure 11f) on average over 100 years. The average increase over 100 years at the Charlottetown (PEI) station was the lowest among analyzed stations at 1.2 °C. For all stations, slopes were significant as *p*-values were below 0.0001. Variability was similar among stations, with standard deviations ranging between 0.8 °C and 1.0 °C. Results also showed that mean annual air temperatures remained relatively high over the past 30 years. For instance, the minimum mean annual temperatures over the past 30 years were 39% (Moncton) to 150% (Miramichi) greater than the minimum mean annual air temperature of the respective series. During the past 30 years the mean annual air temperature was not observed below 3.4 °C (Bathurst in 1993).

Figure 12 shows historical mean summer air temperatures and regression line. Over the past 100 years, summer mean air temperature increased between 1.0 °C (Miramichi, Figure 12b) and 1.7 °C (Saint John, Figure 12e) for NB stations. For weather stations in NS, mean summer temperatures increased by 1.1 °C (Halifax, Figure 12f) and 1.4 °C (Sydney, Figure 12g) on average over 100 years. The average increase over 100 years at the Charlottetown (PEI) station was 1.0 °C. For all stations, slopes were considered significant as *p*-values were below 0.001. Variability in mean summer air temperature was similar among stations, with standard deviations ranging between 0.9 °C and 1.1 °C.

Long-term precipitation data were analyzed using linear regression. Figure 13 shows the long-term precipitation data as well as the associated regression lines. Of the 8 stations, 5 showed positive trends in total annual precipitation, and 4 of the 5 were considered significant (*i.e.*, p-value < 0.05). Statistically significant increases in precipitation ranged between 10 mm per decade (Saint John, Figure 13e, p-value < 0.05) and 31 mm per decade (Moncton, Figure 13d, p-value < 0.0001). The Fredericton site showed a positive slope, however, it was not significant (p-value = 0.842). Decreases in total annual precipitation were observed at 3 stations, Miramichi, Halifax and Charlottetown. The Miramichi station saw a decrease of 12 mm per decade and was considered significant (Figure 13b, p-value < 0.001) whereas the Halifax and Charlottetown stations both showed a 2 mm decrease per decade, however, were not significant (Figure 13f and h; Halifax p-value = 0.525 and Charlottetown p-value = 0.622). High p-values for stations indicate that the slopes of the regression lines are not significantly different than 0. Variability in mean total precipitation was similar among stations, with coefficients of variation (*i.e.*, standard deviation divided by the mean) ranging between 12% (Halifax) and 17% (Moncton).

Figure 14 shows the 30-day moving average high flow dates as well as the regression line. Of the 8 studied stations, 6 showed significant (*i.e.*, p-value < 0.05) negative slopes whereas 2 stations showed non-significant negative slopes, (LaHave River, p-value = 0.55, Figure 14f; and Wilmot River, p-value = 0.67, Figure 14h). The slopes indicate a decrease of approximately

2-3 days per decade (more details below). For spring high flows in New Brunswick, dates varied between day 109 (April 19) and day 155 (June 4; Figure 14). Over the past 30 years, the latest high flow date for NB stations was on day 148 (May 28th) and was observed in 1997 for the Restigouche River. Regression slopes for NB stations ranged between -1.7 days per decade (Nashwaak River, Figure 14d) and -2.3 days per decade (Northwest Miramichi River, Figure 14c). For the NB stations, only two instances occurred where the spring high flow was outside the refined period (*i.e.*, day 40 to 160). Both instances occurred in 2006, where the spring high flow at the Southwest Miramichi and the Nashwaak rivers was later than the refined period. For NS, the St. Marys and Northeast Margaree rivers showed regressions slopes of -3.0 days per decade (p-value < 0.001) and -2.2 days per decade (p-value = 0.009) respectively (Figure 14e and 13g). Spring high flow dates varied more for stations in NS and PEI than in NB. Dates generally ranged between day 41 (February 10th) and day 160 (June 9th). The St. Marys and LaHave rivers were found to have several years where the spring high flow occurred before or after the defined spring period. The St. Marys River had 6 years where the highest moving average was before and 1 year after the defined spring period whereas the LaHave River had 10 years where the highest moving average was before and 2 years after the defined spring period. These results point to a higher variability in the high flow timing where the highest moving average was observed outside of the defined spring high flow period. Such was the case for some NS rivers where the flow regime is influenced by a warmer climate.

Figure 15 shows the highest 30-day average spring magnitude as well as the regression line. Six of the 8 stations showed positive regression slopes, however, only 1 was considered significant (Nashwaak River, 7.3 m^3/s per decade, p-value = 0.017). The 2 stations to show negative regression slopes were the St. Marys and Northeast Margaree rivers, however, these were not significant (St. Marys River, p-value = 0.631, Figure 15e; Northeast Margaree River, p-value = 0.855, Figure 15g). Variability was similar among stations with coefficients of variation between 24% and 28% with the exception of the Wilmot River which showed a coefficient of variation of 36%.

Figure 16 shows the low flow 30-day moving average date as well as the regression line. Among the 8 stations, 4 showed positive regression slopes, *i.e.*, a later low flow date, (Restigouche, Southwest Miramichi, Nashwaak and St. Marys rivers; Figure 16a, b, d and e) while 4 showed negative slopes or earlier low flow dates (Northwest Miramichi, LaHave, Northeast Margaree and Wilmot rivers; Figure 16c, f, g and h). None of the positive slopes were significant (*i.e.*, p-value < 0.05) and only 1 of the 4 negative slopes was significant, Wilmot River (p-value = 0.041, Figure 16h) with a decrease in low flow date of 9.1 days per decade. Fewer events were found to occur outside the defined low flow period when compared to high flows. Only one instance occurred where the low flow 30-day average occurred before the defined low flow period and this was observed at the Restigouche River in 1967. Rivers in NB and PEI showed slightly more variability in low flow dates in comparison to rivers in NS. Standard deviations ranged between 35.8 days (Southwest Miramichi River) and 42.9 days (Wilmot River) for rivers in NB and PEI whereas the standard deviations ranged between 20.9 days (Northeast Margaree River) and 29.6 days (LaHave River) for rivers in NS.

Figure 17 shows the low flow magnitude 30-day moving average as well as the regression line. Negative regression slopes were observed for 4 stations in NB and 1 station in NS. Two stations in NS and the Wilmot River (PEI) showed positive slopes; however, none of the slopes were significant (*i.e.*, p-value < 0.05). Regression p-values ranged between 0.148 (Restigouche River, Figure 17a) and 0.828 (St. Marys River, Figure 17e), indicating that, for all cases, slopes did not differ significantly from 0.

Following the trend analysis on air temperature and discharge, trends were studied for river temperatures. The flow characteristics and air temperature conditions (driven by incoming solar radiation inputs) will have an impact of river temperatures. Significant trends in summer air temperatures will ultimately reflect higher summer river temperatures. The objective of the present study, in terms of river temperatures, is to observe recent trends in summer water temperatures (the time of year where critically high temperature events can occur). As such, Figure 18 presents the time series of summer river temperatures between 1992 and 2020. The Little Southwest Miramichi River (above Catamaran Brook) has the longest time series and shows a significant positive trend (p-value < 0.05) which was most likely influenced by the 1992 (coldest; 16.9 °C) and 2018 (warmest; 22.6 °C) data points. The second site on the Little Southwest Miramichi River (Oxbow; MREAC) showed slightly higher river temperatures; however, did not show a significant trend (p-value $= 0.18$) for data between 2000 and 2020 (missing years). The Nashwaak River temperature site showed similar values to the Little Southwest Miramichi River; however, no significant trends were observed. For the Nashwaak River, the high summer temperature of 2018 (21.8 °C) was similar to 2012 (21.4 °C), 1995 (21.5 °C) and 1999 (21.5 °C). Clearly, all these years experienced high summer temperatures. For the Kedgwick and Restigouche rivers, 2018 experienced the highest summer temperatures (18.0 °C and 22.1 °C, respectively) and these two sites showed a significant increase in temperature between 2002 and 2020. Among the sites that showed a significant increasing trend in summer water temperatures, the slopes reflected increases between 0.8 °C to 2.2 °C per decade.

SUMMARY

In summary, historical hydrometeorological conditions were characterized for Atlantic salmon (*Salmo salar*) rivers within the Maritime provinces. Climate normals (1981-2010) for the 8 studied sites showed that January was the coldest month of the year, with average temperatures between -10.8 °C and -5.4 °C whereas July was the warmest month with average temperatures between 17.1 °C and 19.4 °C. Mean annual air temperatures were found to be between 4.8 °C and 6.6 °C. Precipitation was generally evenly distributed throughout the year. Sites in northern NB showed slightly lower precipitation, i.e., between 1072 mm and 1110 mm, whereas sites in NS showed the highest precipitation, between 1396 mm and 1517 mm.

Spring high flows tended to occur slightly earlier (April) for southern rivers whereas for northern rivers, the spring high flows occurred later (May). Summer low flows generally occurred between July and September. Winter low flows were similar to summer low flows for rivers in NB, however, rivers in NS and PEI showed higher winter flows compared to summer flows. High and low flow frequency analyses were also carried out on daily flows and showed that significant flood and low flow events (i.e., 50- to 100-year events) had occurred in the past 20 years. In addition, timing of extreme high flow events differed among Maritime province rivers. Flood events generally occurred during spring freshet in NB rivers whereas high flow events in NS rivers were more spread out, with most events occurring between November 1 and May 31. For the Wilmot River (PEI), high flow events tended to occur earlier in the year, with most events occurring between January 1 and April 30.

Water temperatures were analyzed in terms of the number of days where the maximum daily temperature exceeded 23 °C. The Little Southwest Miramichi and Nashwaak rivers showed the highest number of days with water temperatures exceeding 23 °C, with averages of 32 days per year and 29 days per year, respectively. The Northeast Upsalquitch and Restigouche rivers showed slightly cooler water temperatures with averages of 9 and 10 days per year, respectively.

Long-term trend analysis showed significant increases in mean annual and mean summer (July and August) air temperatures for all stations with increases between 1.2 °C and 2.0 °C over

100 years on an annual basis and between 1.0 °C and 1.7 °C over 100 years for summer months (July and August). Precipitation data showed a significant increase at 4 of the 8 sites, with increases in total annual precipitation between 10 mm per decade (Saint John) and 31 mm per decade (Moncton). The Miramichi site showed a significant decrease in total annual precipitation of 12 mm per decade.

High and low flows were also analyzed in terms of timing and magnitude using a 30-day moving average. Results showed that high flows tend to occur earlier within the year, on average. Significant regression slopes were observed at 6 of the 8 sites and indicate earlier spring high flows by 1.7 days to 3.0 days per decade, on average. Both positive (6 out of 8) and negative (2 out of 8) regression slopes were observed for high flow magnitude, however, only 1, the Nashwaak River, was significant with an increase of 7.3 m^3/s per decade, on average.

Fewer significant trends were observed for low flow timing. Only 1 of the 8 stations showed a significant trend, the Wilmot River, which showed a decrease in low flow date (i.e., occurs earlier in the year) of 9.1 days per decade. No significant trends were observed for low flow magnitudes.

Past water temperature data showed significant increases in summer water temperature at three sites. The Little Southwest Miramichi River (above Catamaran Brook), which has the longest series, showed a significant increase in water temperature between 1992 and 2018, however, the Little Southwest Miramichi River (at Oxbow) site did not show a significant increase between 2000 and 2020. The Restigouche and Kedgwick rivers, the 2 northernmost stations, showed significant increases in summer water temperatures between 2003 and 2020 of 2.0 °C and 2.2 °C per decade, respectively (as indicated by the regression slopes).

REFERENCES CITED

Caissie, D., C. Breau, J. Hayward, and P. Cameron. 2013. Water temperature characteristics of the Miramichi and Restigouche Rivers. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/165. vi + 31 p.

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

Elwood, J.W., and Waters, T.F. 1969. Effects of flood on food consumption and production rates of a stream brook trout population. Trans. Amer. Fish. Soc. 98: 253-262.

Erman, D.C., Andrews, E.D., and Yoder-Williams, M. 1988. Effects of winter floods on fishes in the Sierra Nevada. Can. J. Fish. Aquat. Sci. 45: 2195-2200.

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

Lund, S.G., Caissie, D., Cunjak, R.A., Vijayan, M.M., and Tufts, B.L. 2002. The effects of environmental heat stress on heat-shock mRNA and protein expression in Miramichi Atlantic salmon (*Salmo salar*) parr. Can. J. Fish. Aquat. Sci. 59: 1553-1562.

TABLES

Table 1. Analyzed meteorological stations for air temperature and precipitation in the Maritime provinces.

Station Name	Station ID	Province	Year start	Year end (air temperature)	Year end (precipitation)
Bathurst	8100505	NB	1922	2020	2012
Miramichi	8100989	NB	1873	2020	2004
Fredericton	8101605	NB	1871	2020	2009
Moncton	8103201	NB	1898	2020	2011
Saint John	8104901	NB	1871	2020	2011
Halifax	8202251	NS	1871	2020	2011
Sydney	8205702	NS	1870	2020	2013
Charlottetown	8300301	PEI	1872	2020	2011

Table 2. Analyzed rivers in the Maritime provinces with drainage area and flow characteristics.

River	Station ID	Province	Drainage area (km^2)	Years of data	Number of years	MAF* (m^3/s)	Runoff (mm)
Restigouche River below Kedgwick River	01BC001	NB	3160	1963-2019	57	68.7	686
Southwest Miramichi River	01BO001	NB	5050	1962-2018	57	121	755
Northwest Miramichi River	01BQ001	NB	948	1962-2019	58	22.1	735
Nashwaak River at Durham Bridge	01AL002	NB	1450	1962-2019	58	37.1	807
St. Marys River at Stillwater	01EO001	NS	1350	1916-2018	103	43.0	1003
LaHave River at West Northfield	01EF001	NS	1250	1916-2018	103	14.9	376
Northeast Margaree River at Margaree Valley	01FB001	NS	368	1929-2018	90	17.0	1460
Wilmot River Near Wilmot Valley	01CB004	PEI	45.4	1972-2019	48	0.950	660

*MAF = Mean Annual Flow

Table 3. Climate normals (1981-2010) for the stations analyzed in the Maritime provinces

Station name	Province	Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Extreme
Bathurst	NB	Air temp. min, °C	-16.2	-15.1	-9	-1.9	3.6	9.5	13.2	12.1	7.4	1.7	-3.4	-10.4	na	-35.6
		Air temp. max, °C	-5.5	-3.7	1.5	8.3	15.7	22.2	24.8	24.3	19.6	11.8	4.9	-1.5	na	37.4
		Air temp. Mean, °C	-10.8	-9.4	-3.8	3.2	9.7	15.9	19.1	18.2	13.5	6.8	0.8	-6	4.8	na
		Precipitation, mm	85	67	89	78	103	97	101	82	84	123	104	98	1110	na
Miramichi	NB	Air temp. min, °C	-16.6	-14.9	-8.9	-2.1	3.7	9.3	13	12.3	7.4	1.5	-3.4	-11.1	na	-35
		Air temp. max, °C	-5	-2.8	2.1	8.5	16.3	22.2	25.2	24.6	19.5	12.3	4.9	-1.3	na	37.8
		Air temp. Mean, °C	-10.8	-8.9	-3.4	3.2	10	15.7	19.1	18.5	13.5	6.9	0.7	-6.2	4.9	na
		Precipitation, mm	87	71	91	85	100	86	100	93	85	90	101	85	1072	na
Fredericton	NB	Air temp. min, °C	-14.4	-12.8	-7.2	-0.4	5.1	10.1	13.3	12.6	8.3	2.8	-2	-9.5	na	-38.9
		Air temp. max, °C	-4.4	-2.1	2.8	9.9	17.6	22.7	25.4	24.5	19.6	12.8	5.5	-1	na	38.9
		Air temp. Mean, °C	-9.4	-7.5	-2.2	4.8	11.3	16.4	19.4	18.6	14	7.8	1.8	-5.3	5.8	na
		Precipitation, mm	102	70	90	82	104	86	89	86	95	90	110	92	1095	na
Moncton	NB	Air temp. min, °C	-14	-12.7	-7.8	-1.4	4	9.1	12.9	12.2	7.7	2.3	-2.4	-9.4	na	-32.2
		Air temp. max, °C	-3.7	-2.4	2	8.5	16	21.2	24.7	24	19.5	12.8	6.1	-0.2	na	37.2
		Air temp. Mean, °C	-8.9	-7.6	-2.9	3.5	10	15.2	18.8	18.2	13.6	7.6	1.9	-4.8	5.4	na
		Precipitation, mm	103	91	116	98	97	95	92	81	94	113	107	114	1200	na
Saint John	NB	Air temp. min, °C	-13.3	-12.6	-7.4	-1.2	3.9	8.4	11	11.2	7.7	2.8	-1.9	-9.3	na	-36.7
		Air temp. max, °C	-2.5	-1.5	2.4	8.5	15	19.6	22.6	22.4	18.2	12.3	6.4	0.5	na	34.4
		Air temp. Mean, °C	-7.9	-7.1	-2.5	3.7	9.5	14	17.1	16.8	13	7.6	2.3	-4.4	5.2	na
		Precipitation, mm	124	91	108	105	110	101	88	82	106	116	134	130	1296	na
Halifax	NS	Air temp. min, °C	-10.4	-9.7	-5.7	-0.3	4.6	9.7	13.7	13.7	9.7	4.2	-0.4	-6.4	na	-28.5
		Air temp. max, °C	-1.3	-0.6	3.1	9.1	15.3	20.4	23.8	23.6	19.4	13.1	7.3	1.7	na	35
		Air temp. Mean, °C	-5.9	-5.2	-1.3	4.4	10	15.1	18.8	18.7	14.6	8.7	3.5	-2.4	6.6	na
		Precipitation, mm	134	106	120	115	112	96	96	94	102	125	154	143	1396	na
Sydney	NS	Air temp. min, °C	-9.6	-10.3	-6.7	-1.6	2.7	7.7	12.6	13.1	9.1	4.3	0.2	-5	na	-27.3
		Air temp. max, °C	-1.1	-1.5	1.5	6.6	13.1	18.6	23.1	22.9	18.8	12.6	7.3	2.1	na	35.5
		Air temp. Mean, °C	-5.4	-5.9	-2.6	2.5	7.9	13.2	17.9	18	14	8.5	3.8	-1.5	5.9	na
		Precipitation, mm	153	128	130	133	103	97	89	100	119	143	156	167	1517	na
Charlottetown	PEI	Air temp. min, °C	-12.1	-11.7	-7	-1.2	4.1	9.6	14.1	13.7	9.6	4.4	-0.5	-7	na	-30.5
		Air temp. max, °C	-3.4	-2.9	0.9	7.2	14.3	19.4	23.3	22.8	18.6	12.3	6.3	0.5	na	34.4
		Air temp. Mean, °C	-7.7	-7.3	-3.1	3.1	9.2	14.5	18.7	18.3	14.1	8.3	2.9	-3.3	5.7	na
		Precipitation, mm	101	83	86	84	91	99	80	96	96	112	113	118	1158	na

Table 4. Mean monthly discharge and discharge per unit area at the studied Atlantic salmon rivers

	Discharge (m^3/s)												
River	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
Restigouche River	25.1	19.4	24.4	155	248	70.5	46.2	36.1	32.8	50.8	65.5	47.4	68.7
Southwest Miramichi River	72.2	55.2	77.5	337	295	105	64.5	55.3	51.7	87.5	132	117	121
Northwest Miramichi River	10.0	8.32	12.9	61.5	65.0	19.8	11.2	10.8	8.80	15.8	21.6	19.0	22.1
Nashwaak River	23.2	19.1	30.8	113	77.3	28.4	17.7	13.9	14.7	27.0	41.9	37.8	37.1
St. Marys River	50.7	42.1	56.1	88.8	54.1	24.2	14.6	14.6	17.5	35.0	58.3	60.0	43.0
LaHave River	46.3	39.3	54.0	73.3	38.3	20.3	11.1	8.51	9.31	21.1	45.5	52.4	34.9
Northeast Margaree River	15.0	11.0	12.3	28.7	41.4	14.8	6.67	7.41	9.61	16.1	22.5	19.8	17.1
Wilmot River	1.14	1.01	1.63	1.95	1.14	0.714	0.542	0.466	0.476	0.563	0.749	1.00	0.952

	Discharge expressed in L/s per km^2												
River	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
Restigouche River	7.94	6.13	7.72	49.1	78.6	22.3	14.6	11.4	10.4	16.1	20.7	15.0	21.7
Southwest Miramichi River	14.3	10.9	15.3	66.8	58.3	20.8	12.8	10.9	10.2	17.3	26.1	23.2	24.0
Northwest Miramichi River	10.6	8.78	13.6	64.9	68.6	20.9	11.8	11.4	9.28	16.6	22.8	20.1	23.3
Nashwaak River	16.0	13.2	21.2	78.2	53.3	19.6	12.2	9.60	10.1	18.6	28.9	26.1	25.6
St. Marys River	37.5	31.2	41.6	65.8	40.1	17.9	10.8	10.8	12.9	26.0	43.2	44.4	31.8
LaHave River	37.1	31.4	43.2	58.6	30.6	16.2	8.89	6.81	7.45	16.9	36.4	41.9	27.9
Northeast Margaree River	40.9	29.8	33.4	78.0	112	40.3	18.1	20.1	26.1	43.6	61.1	53.9	46.6
Wilmot River	25.1	22.1	35.9	43.1	25.1	15.7	11.9	10.3	10.5	12.4	16.5	22.1	21.0

Table 5. High and low flow frequency analyses for the studied Atlantic salmon rivers within the Maritime provinces.

	High flow (m^3/s) Recurrence interval, T (years)						High flow (L/s per km^2) Recurrence interval, T (years)					
River	**2**	**5**	**10**	**20**	**50**	**100**	**2**	**5**	**10**	**20**	**50**	**100**
Restigouche River	589	786	914	1035	1188	1302	186	249	289	327	376	412
Southwest Miramichi River	913	1226	1426	1613	1848	2018	181	243	282	319	366	400
Northwest Miramichi River	194	279	341	406	499	575	205	294	360	429	526	606
Nashwaak River	352	512	629	750	922	1063	243	353	434	517	636	733
St. Marys River	391	516	602	685	795	880	290	383	446	507	589	652
LaHave River	209	300	372	450	567	668	167	240	298	360	454	534
Northeast Margaree River	166	222	261	300	354	396	452	603	710	817	962	1077
Wilmot River	11.4	16.9	21.5	26.8	35.3	43.2	252	372	473	591	778	952

	Low flow (m^3/s) Recurrence interval, T (years)						Low flow (L/s per km^2) Recurrence interval, T (years)					
River	**2**	**5**	**10**	**20**	**50**	**100**	**2**	**5**	**10**	**20**	**50**	**100**
Restigouche River	9.890	7.963	7.089	6.463	5.876	5.559	3.1	2.5	2.2	2.0	1.9	1.8
Southwest Miramichi River	18.65	14.65	13.08	12.06	11.22	10.81	3.7	2.9	2.6	2.4	2.2	2.1
Northwest Miramichi River	2.688	2.095	1.853	1.692	1.555	1.486	2.8	2.2	2.0	1.8	1.6	1.6
Nashwaak River	3.901	2.939	2.608	2.414	2.271	2.209	2.7	2.0	1.8	1.7	1.6	1.5
St. Marys River	1.682	0.756	0.476	0.328	0.229	0.191	1.2	0.56	0.35	0.24	0.17	0.14
LaHave River	1.592	0.630	0.349	0.204	0.110	0.075	1.3	0.50	0.28	0.16	0.09	0.06
Northeast Margaree River	3.049	2.329	1.989	1.737	1.493	1.356	8.3	6.3	5.4	4.7	4.1	3.7
Wilmot River	0.310	0.245	0.214	0.190	0.167	0.153	6.8	5.4	4.7	4.2	3.7	3.4

FIGURES

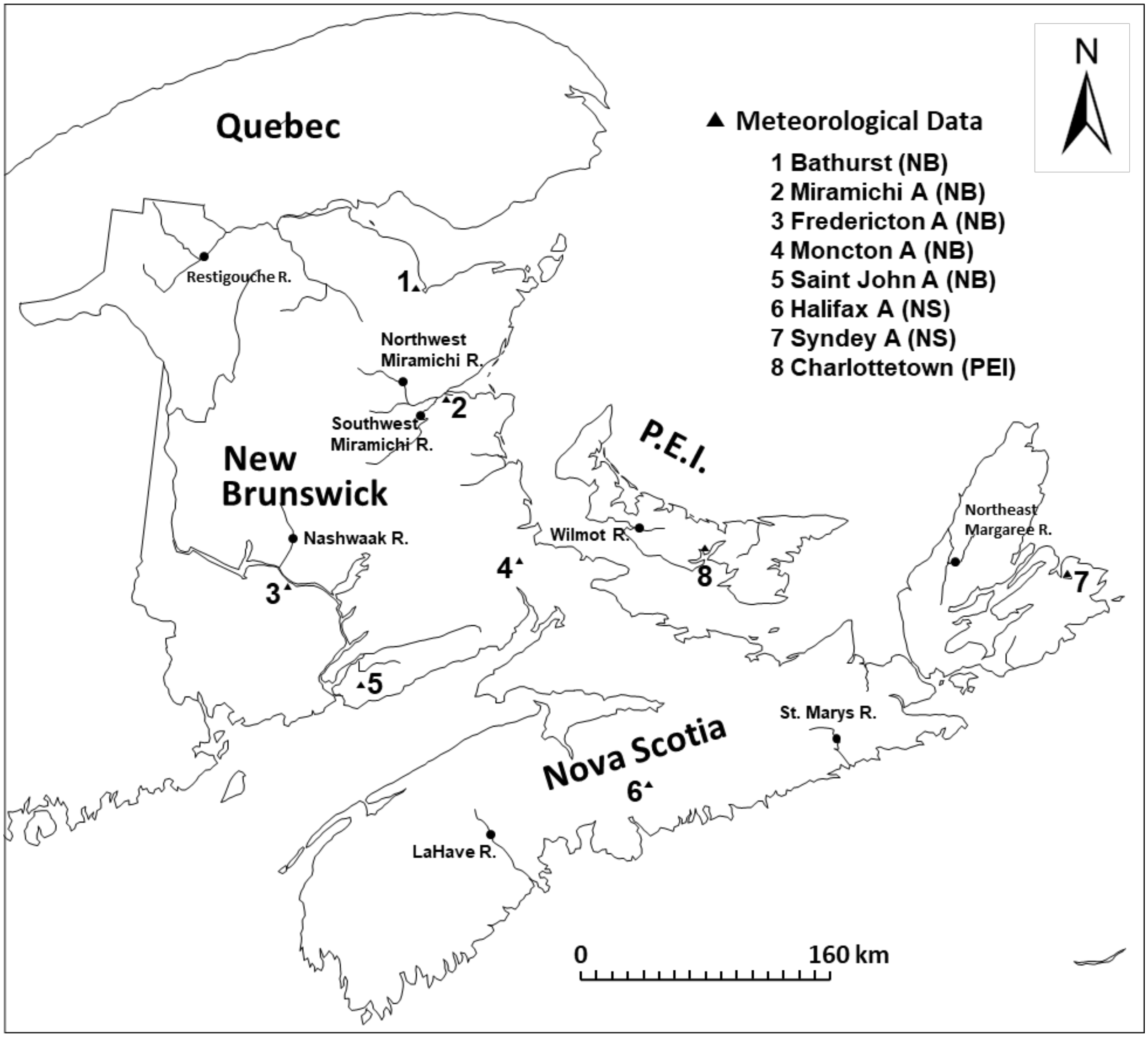

Figure 1. Location of meteorological and hydrometric stations of selected rivers within the Maritime provinces.

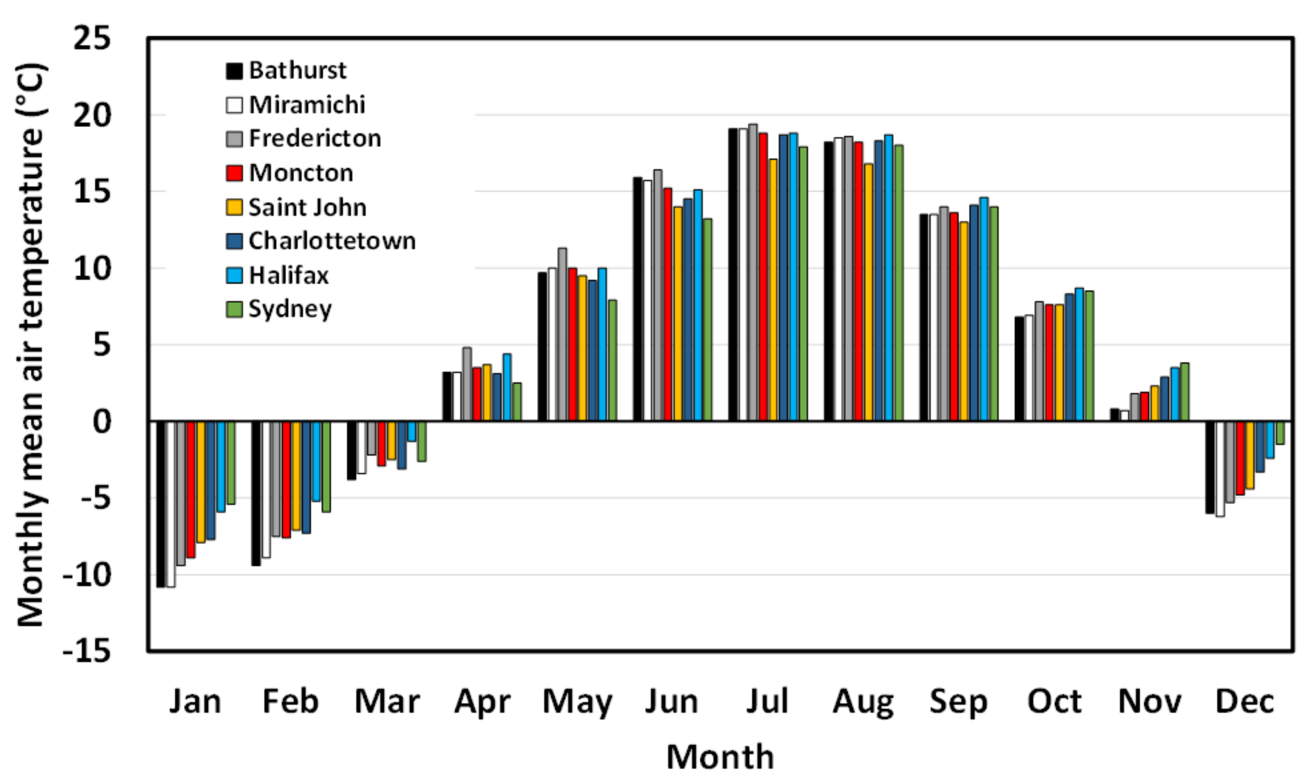

Figure 2. Monthly mean air temperatures at various stations across the Maritime provinces.

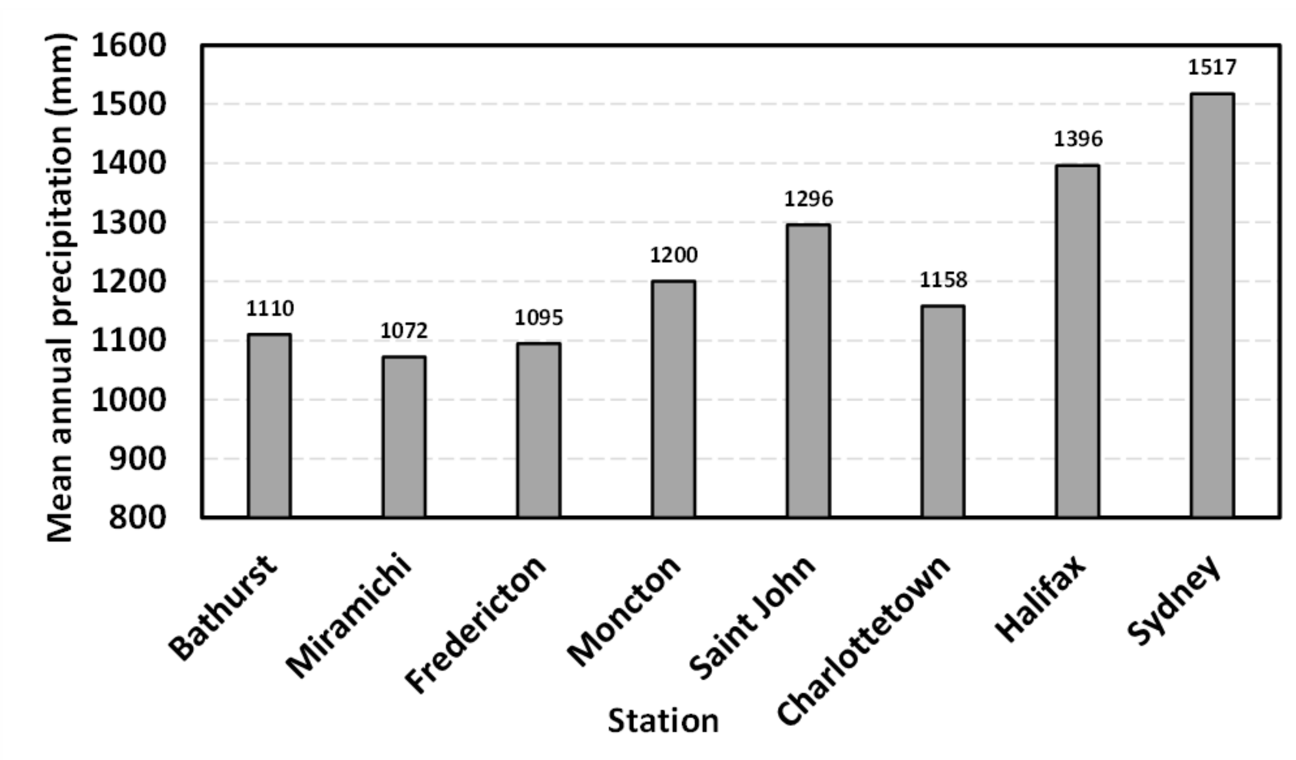

Figure 3. Mean annual precipitation at various stations across the Maritime provinces

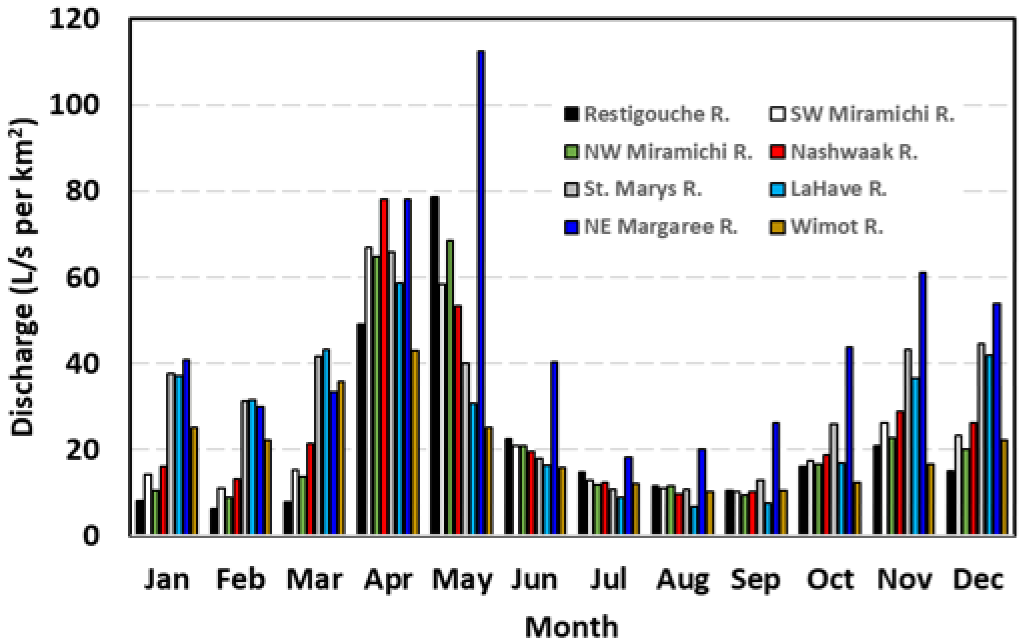

Figure 4. Results of monthly flows expressed in discharge per unit area (L/s per km²) at the studied river in the Maritime provinces.

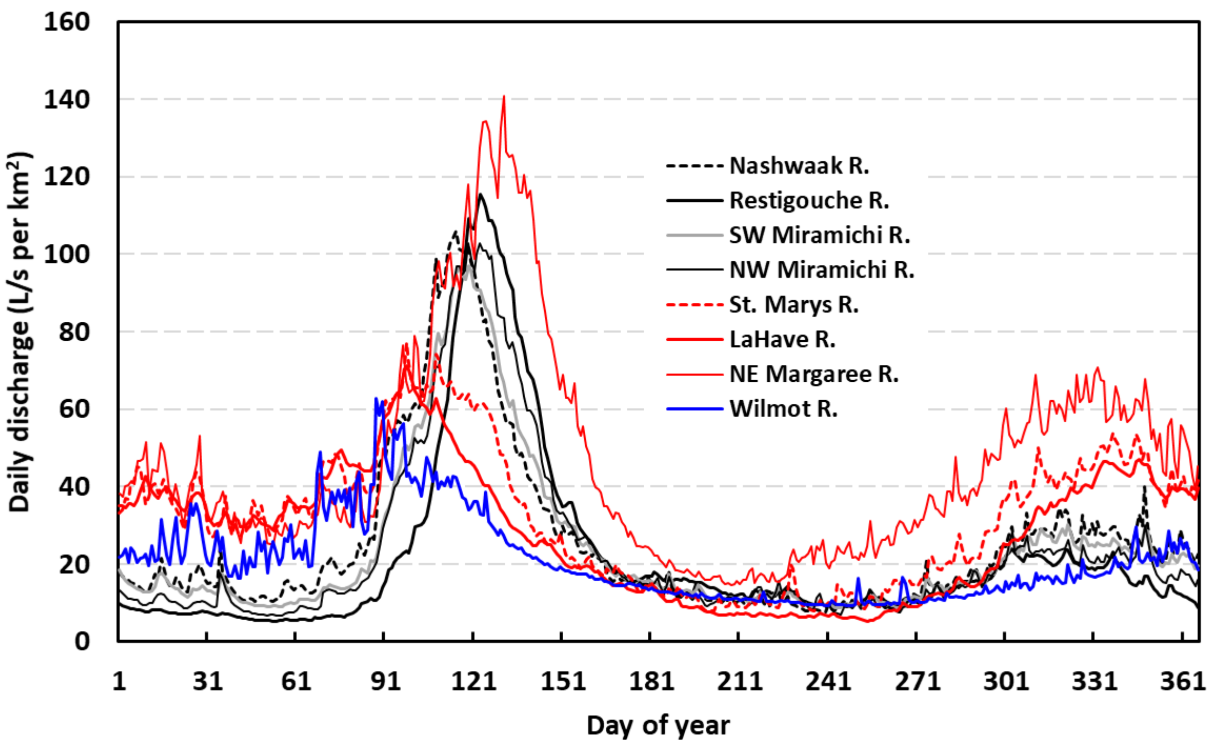

Figure 5. Daily discharge expressed in L/s per km² for the studied rivers in the Maritime provinces.

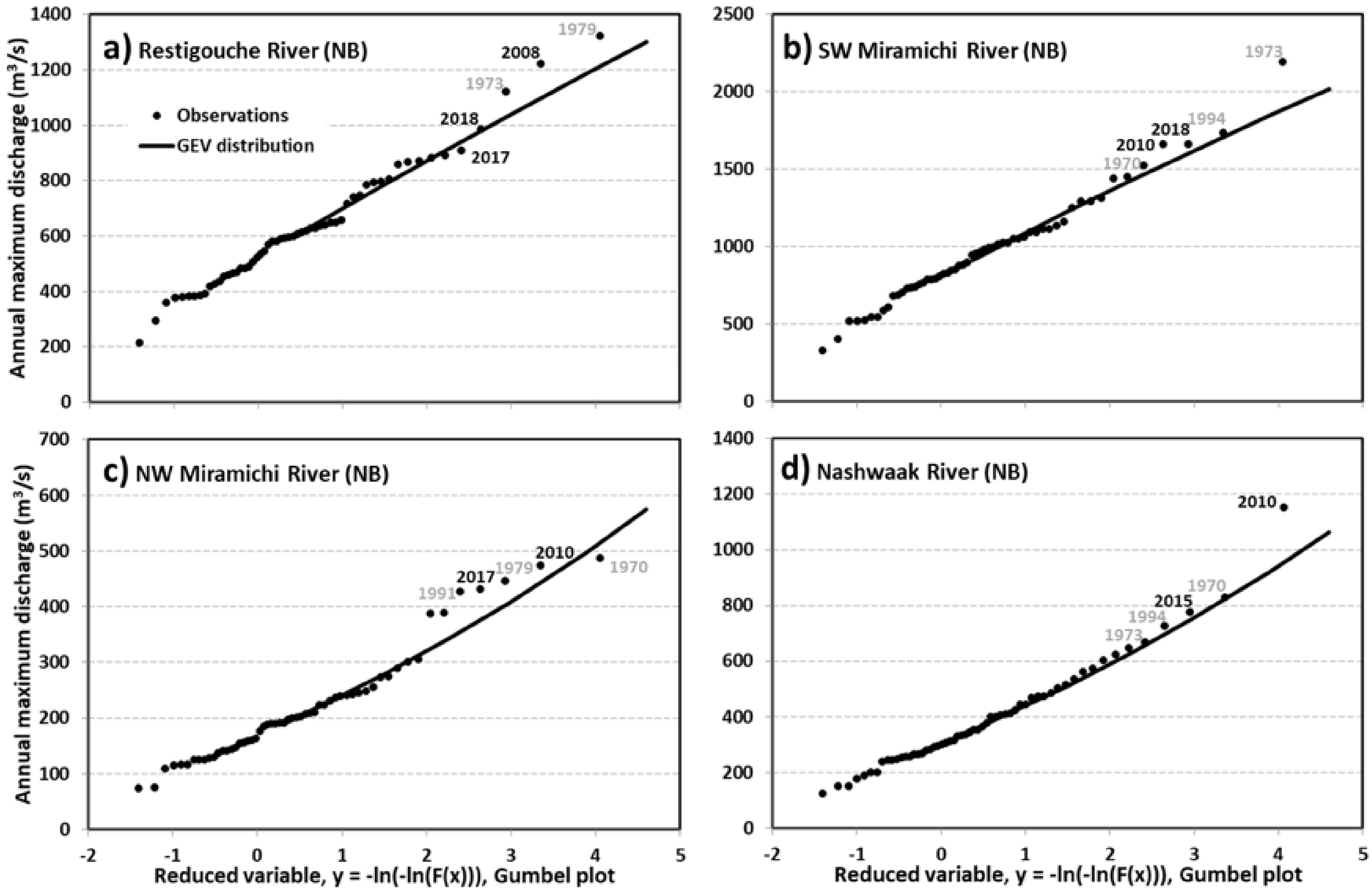

Figure 6. High flow frequency analysis for the studied Atlantic salmon rivers in the Maritime provinces. The year of the 5 highest floods are identified (most recent in black and later in grey).

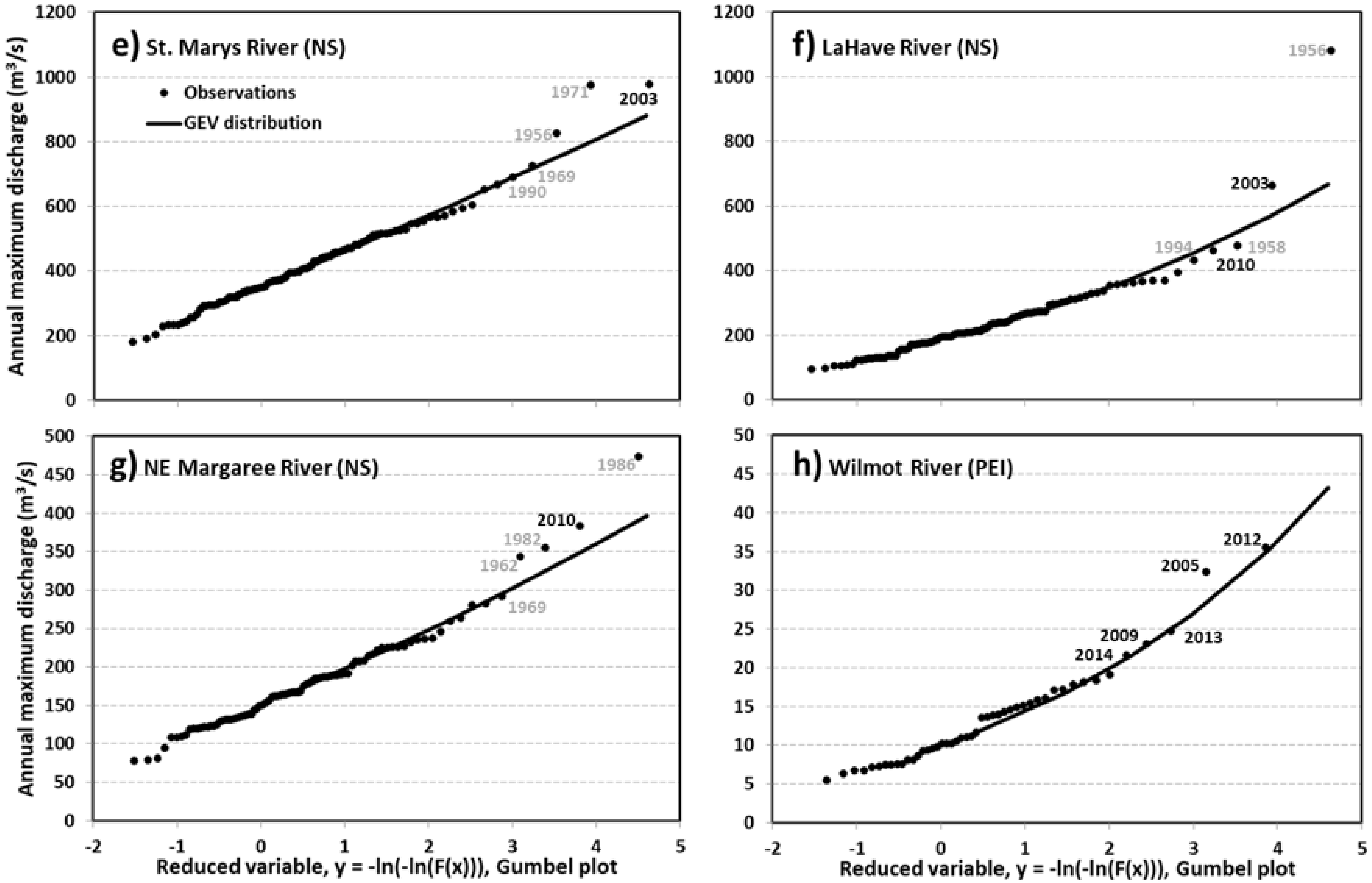

Figure 6 (Continued). High flow frequency analysis for the studied Atlantic salmon rivers in the Maritime provinces. The year of the 5 highest floods are identified (most recent in black and later in grey).

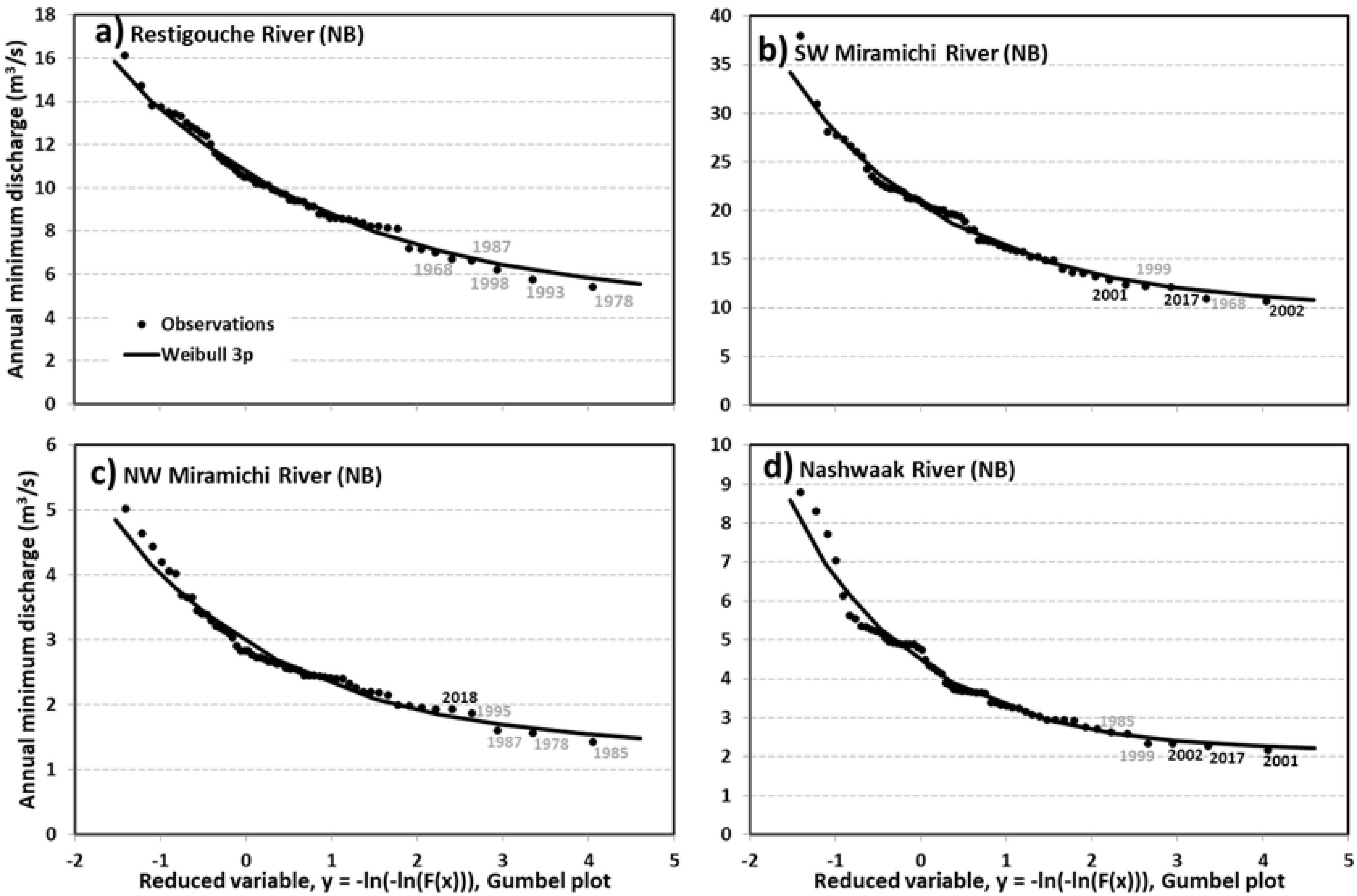

Figure 7. Low flow frequency analysis for the studied Atlantic salmon rivers in the Maritime provinces. The year of the 5 lowest flow are identified (most recent in black and later in grey)

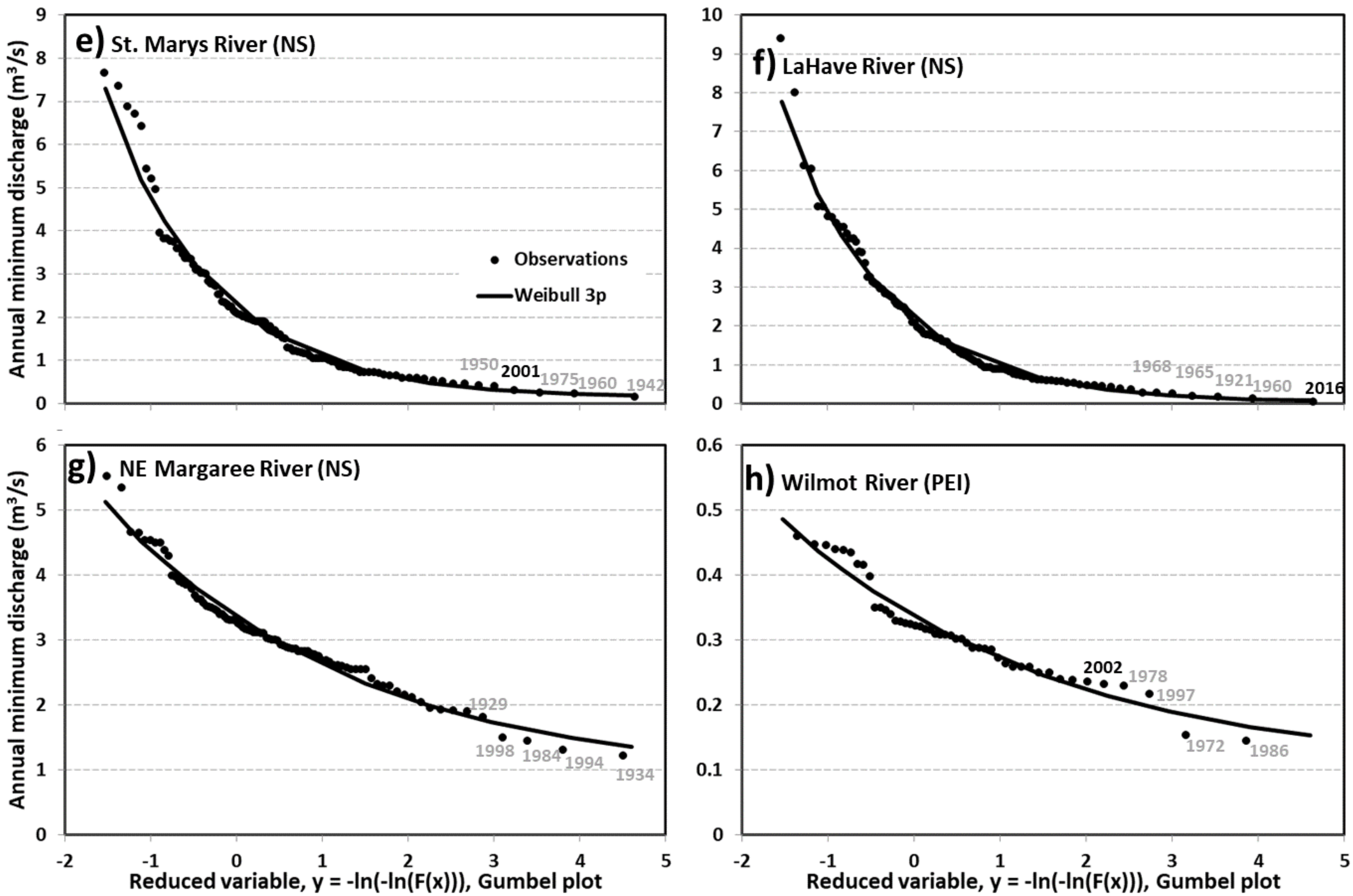

Figure 7 (Continued). Low flow frequency analysis for the studied Atlantic salmon rivers in the Maritime provinces. The year of the 5 lowest flow are identified (most recent in black and later in grey).

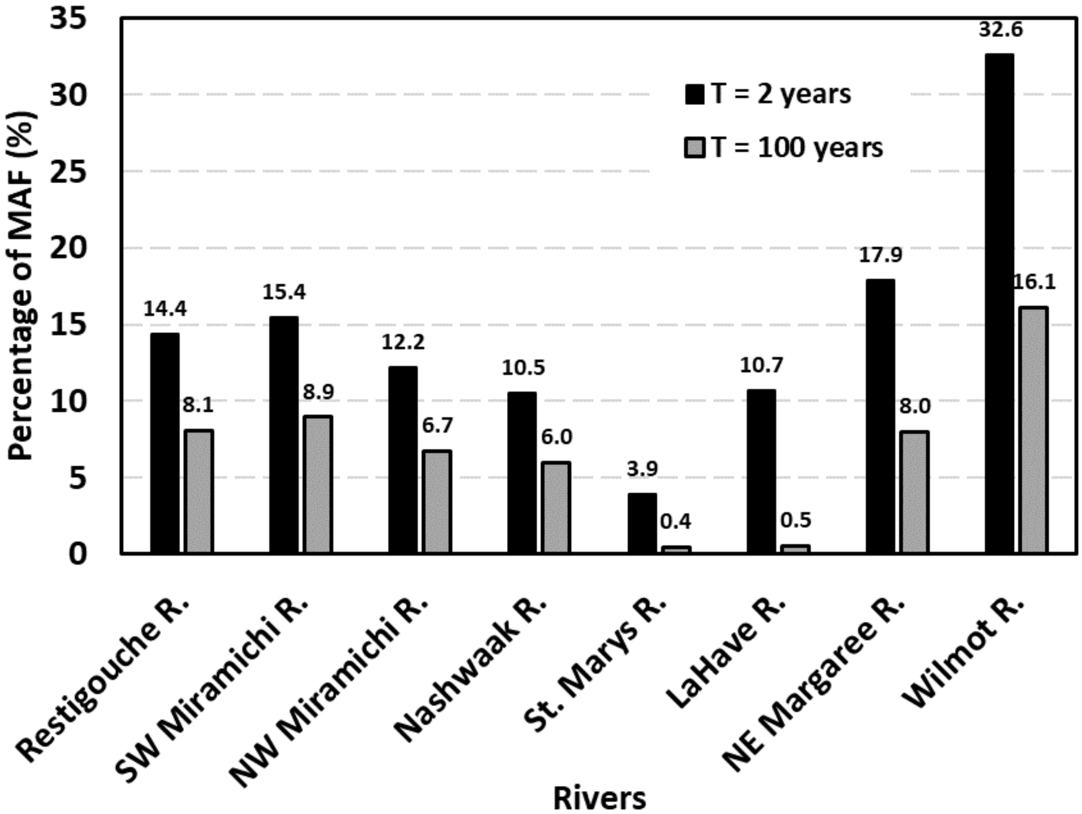

Figure 8. Results of the 2-year and 100-year low flows expressed as a percentage of the mean annual flow (MAF) for the studied Atlantic salmon rivers in the Maritime provinces.

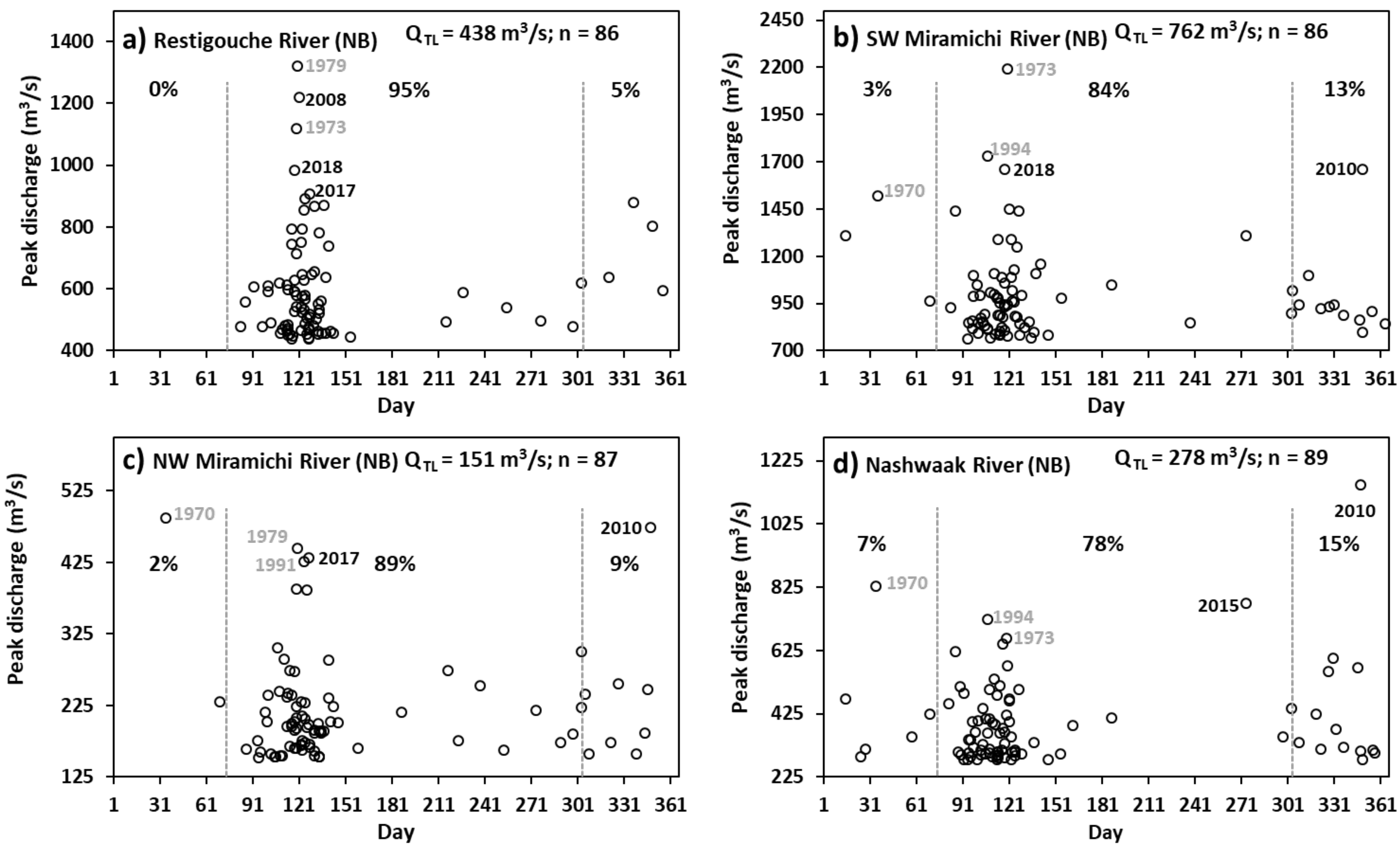

Figure 9. Timing of high flow events for the studied Atlantic salmon rivers in the Maritime provinces. (TL = Truncation level; n = data points)

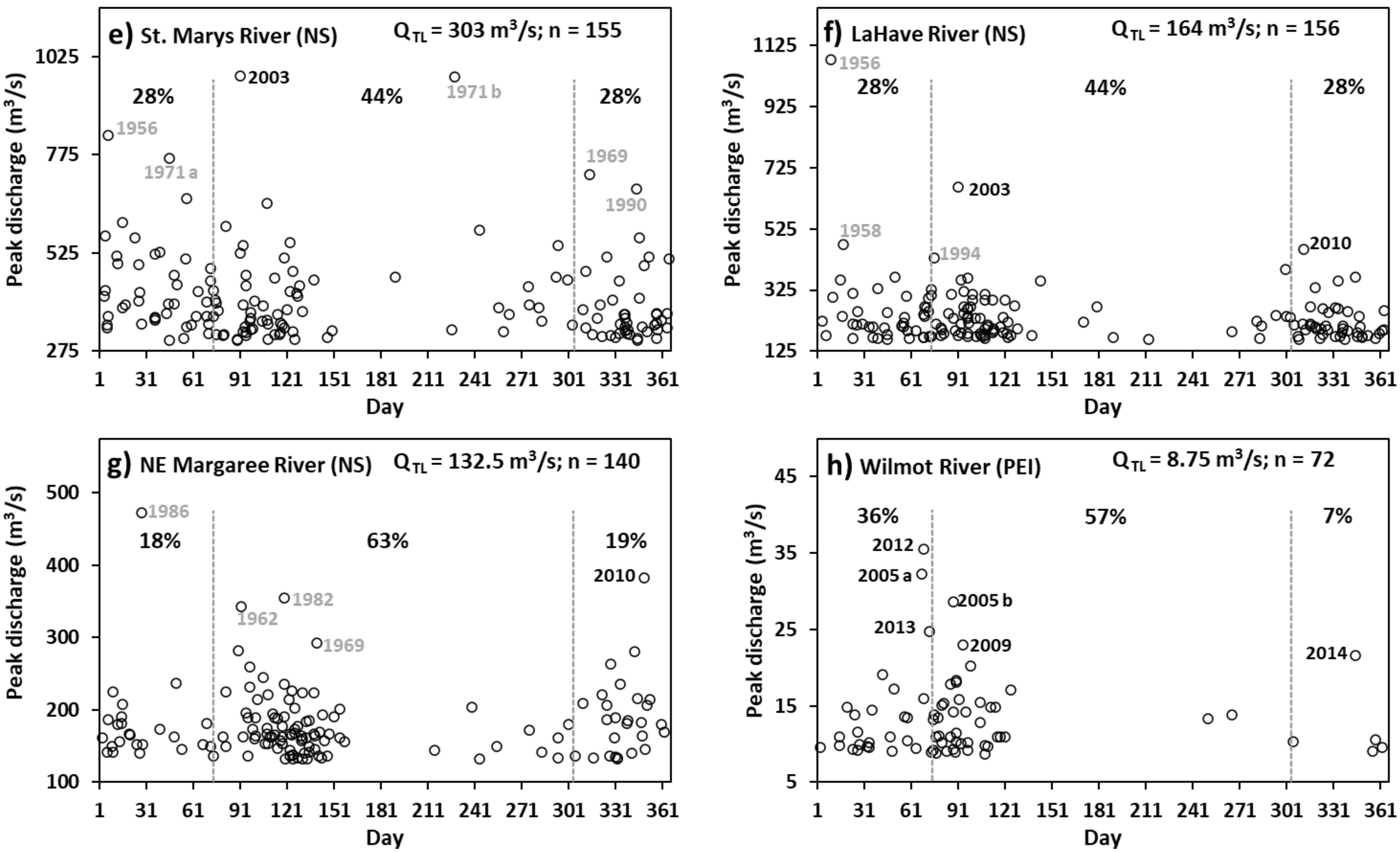

Figure 9 (Continued). Timing of high flow events for the studied Atlantic salmon rivers in the Maritime provinces. (TL = Truncation level; n = data points)

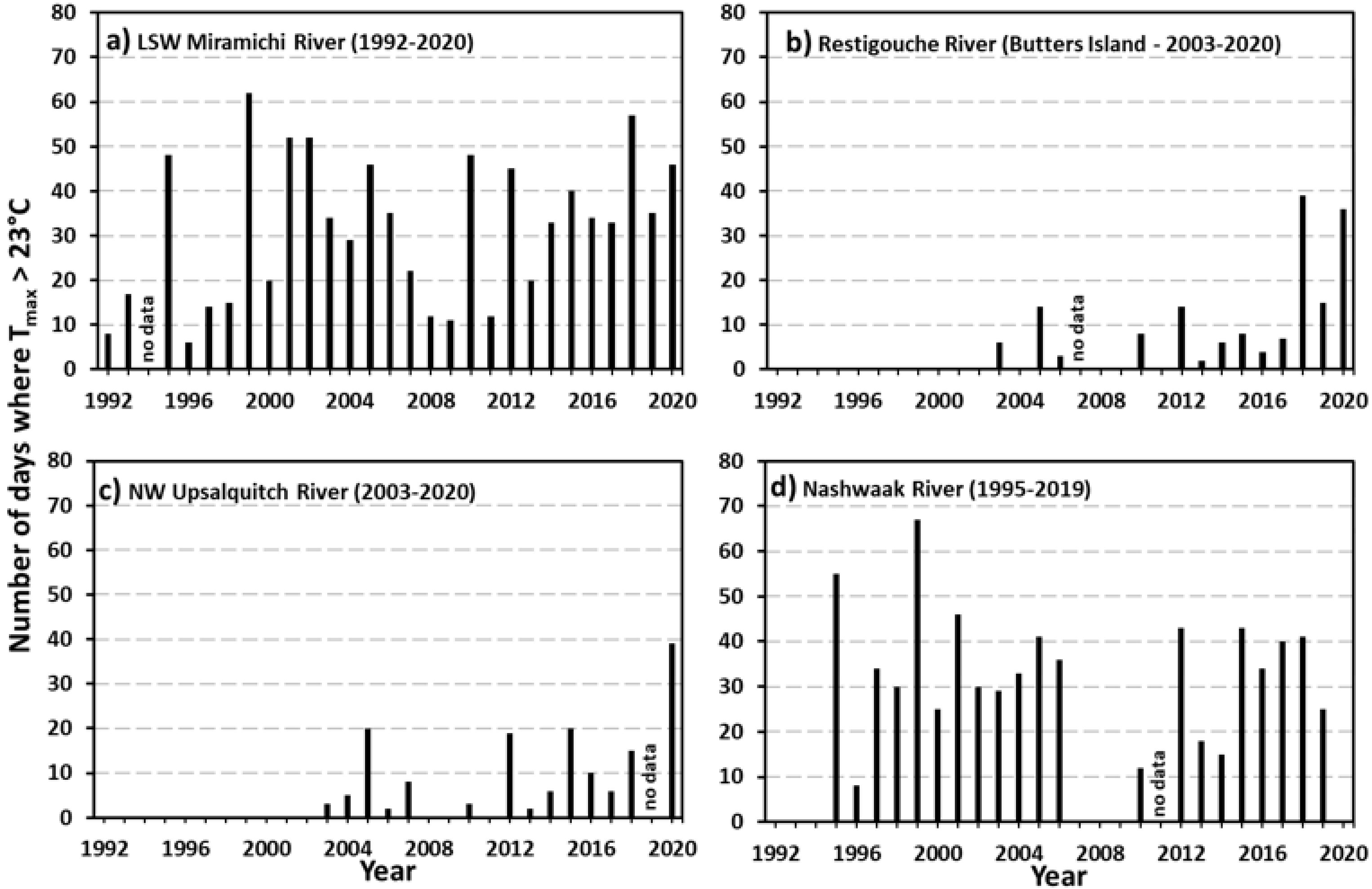

Figure 10. Results of the number of days where Tmax > 23 °C at selected sites within the Maritime provinces between 1992 and 2020.

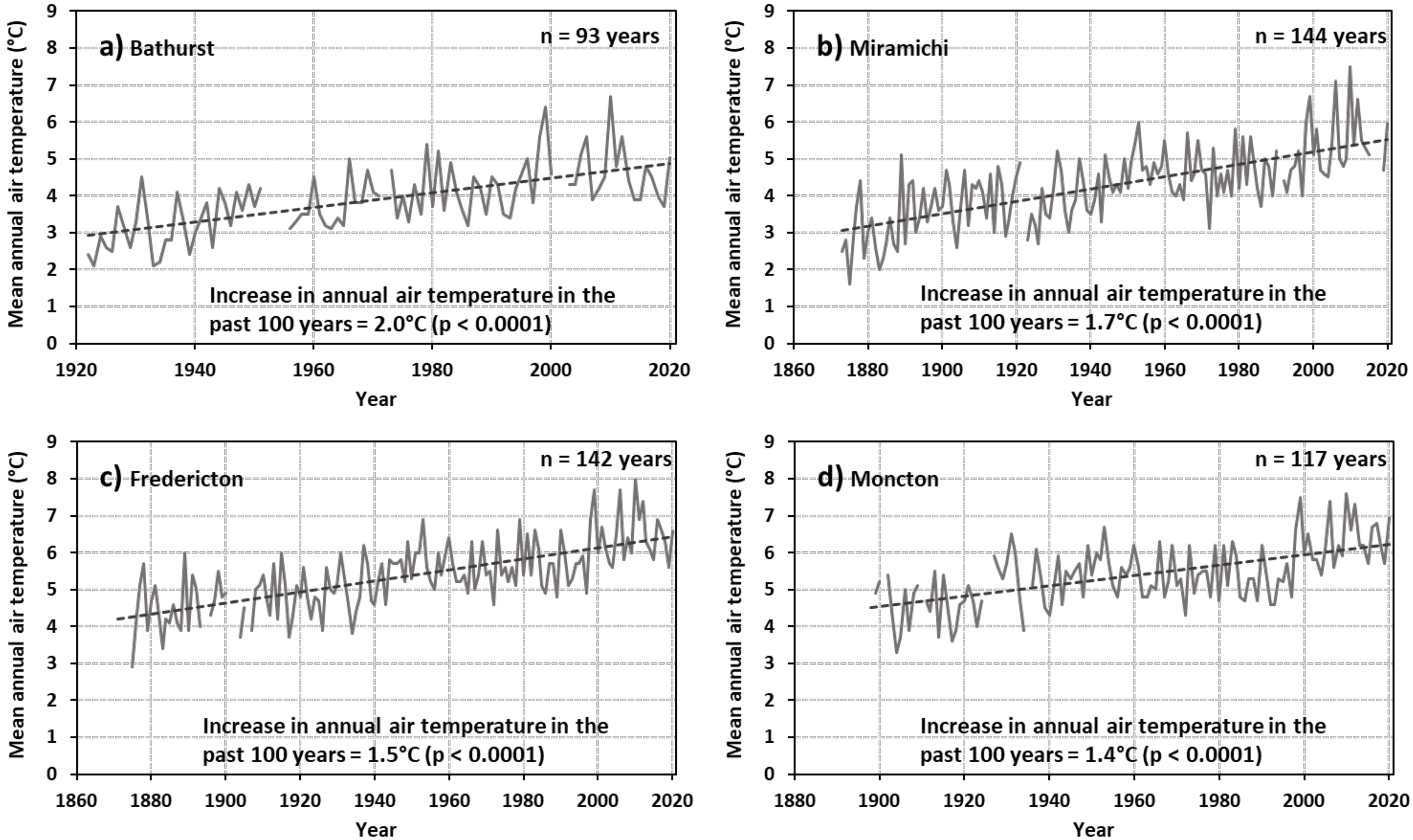

Figure 11. Long-term mean annual air temperature for selected stations in the Maritime provinces.

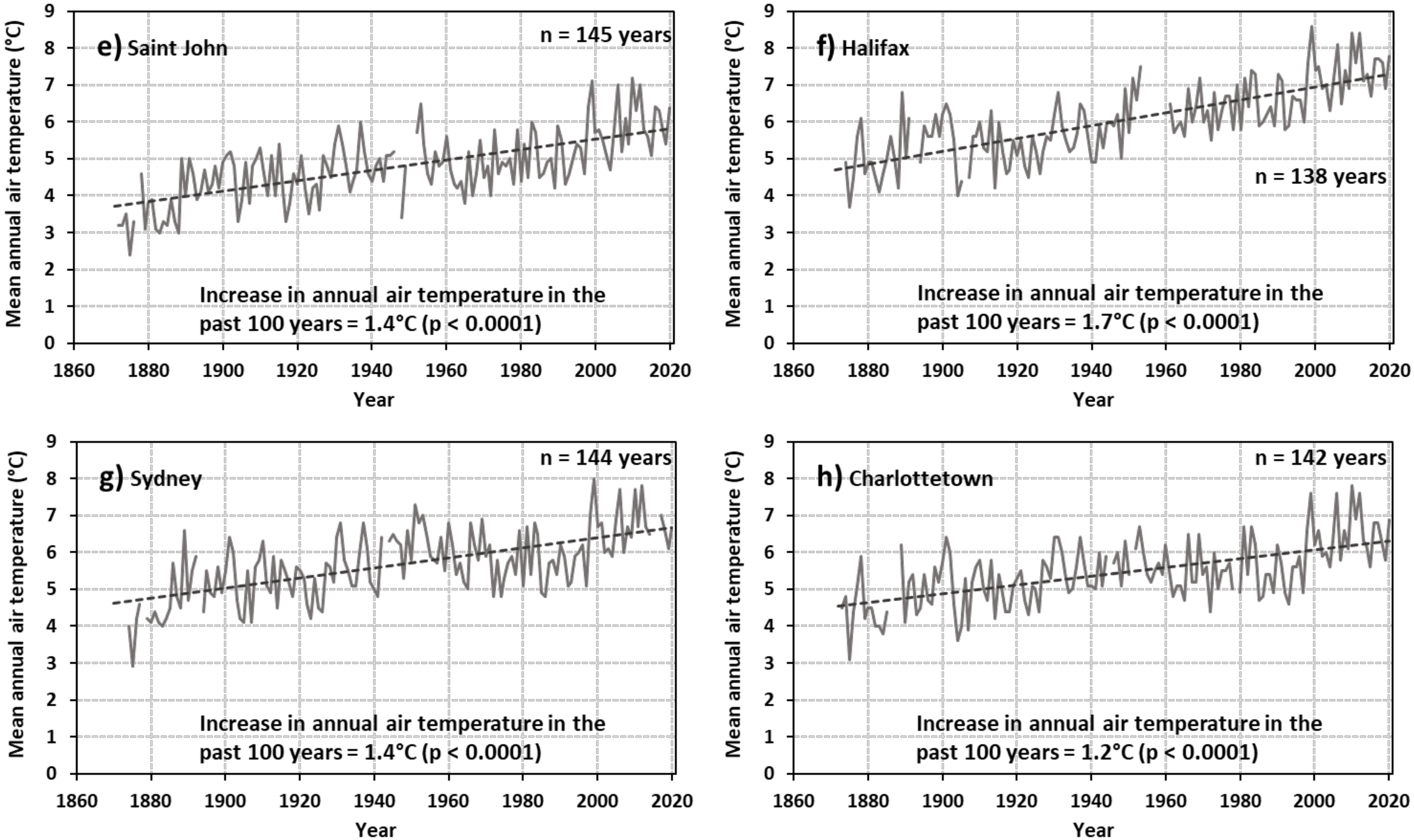

Figure 11 (Continued). Long-term mean annual air temperature for selected stations in the Maritime provinces.

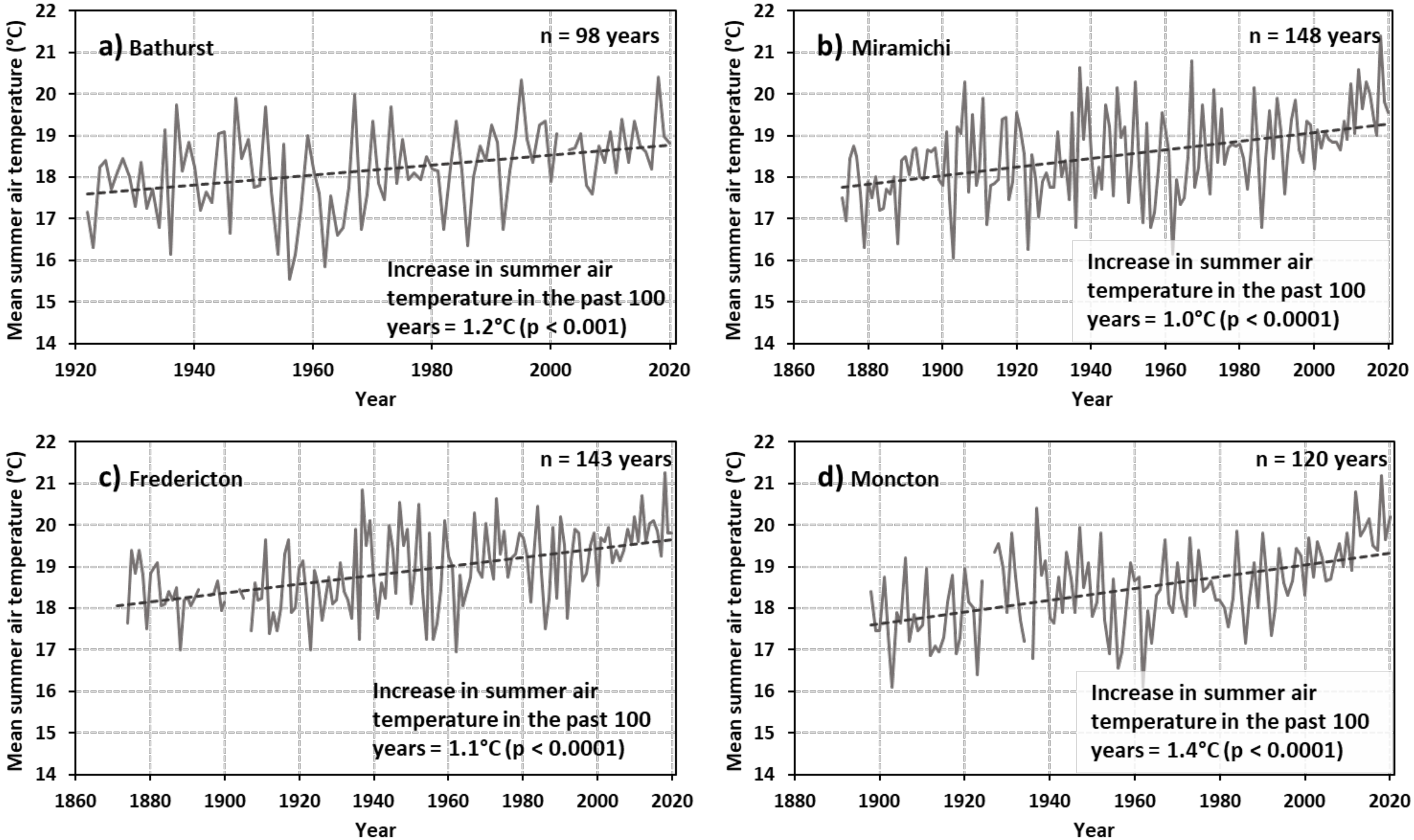

Figure 12. Long-term mean summer air temperature for selected stations in the Maritime provinces (summer = July and August).

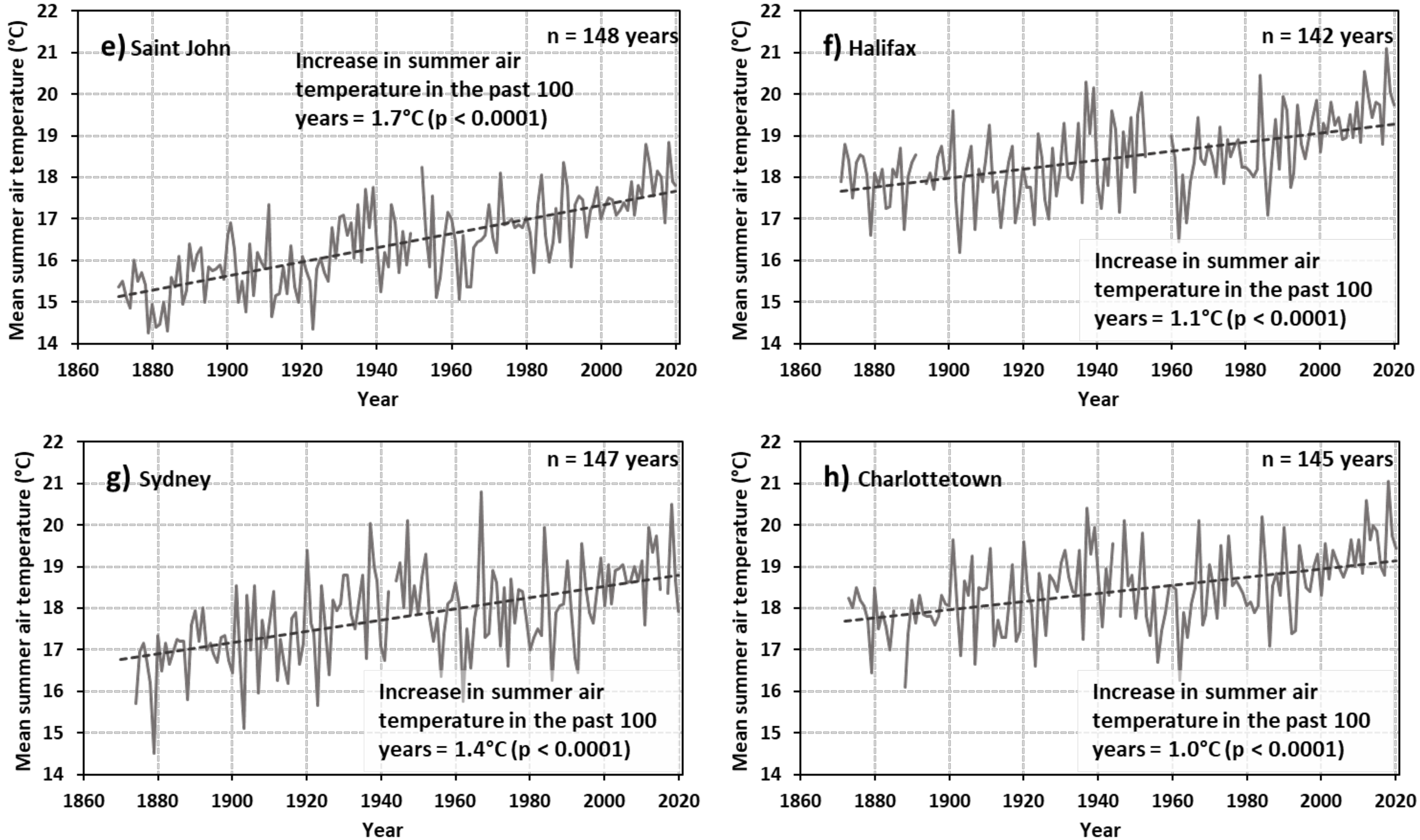

Figure 12 (Continued). Long-term mean summer air temperature for selected stations in the Maritime provinces (summer = July and August).

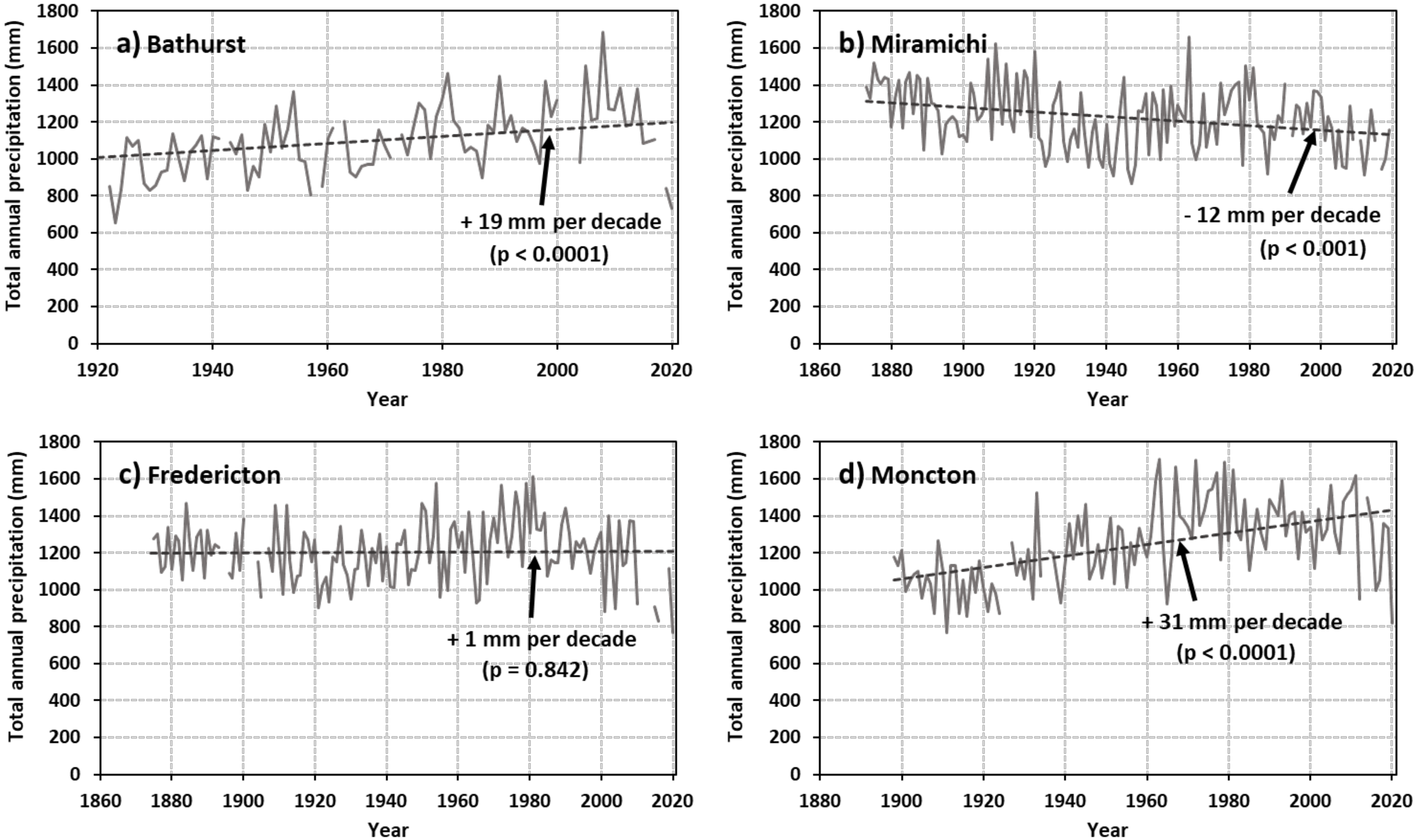

Figure 13. Long-term total annual precipitation for selected stations in the Maritime provinces.

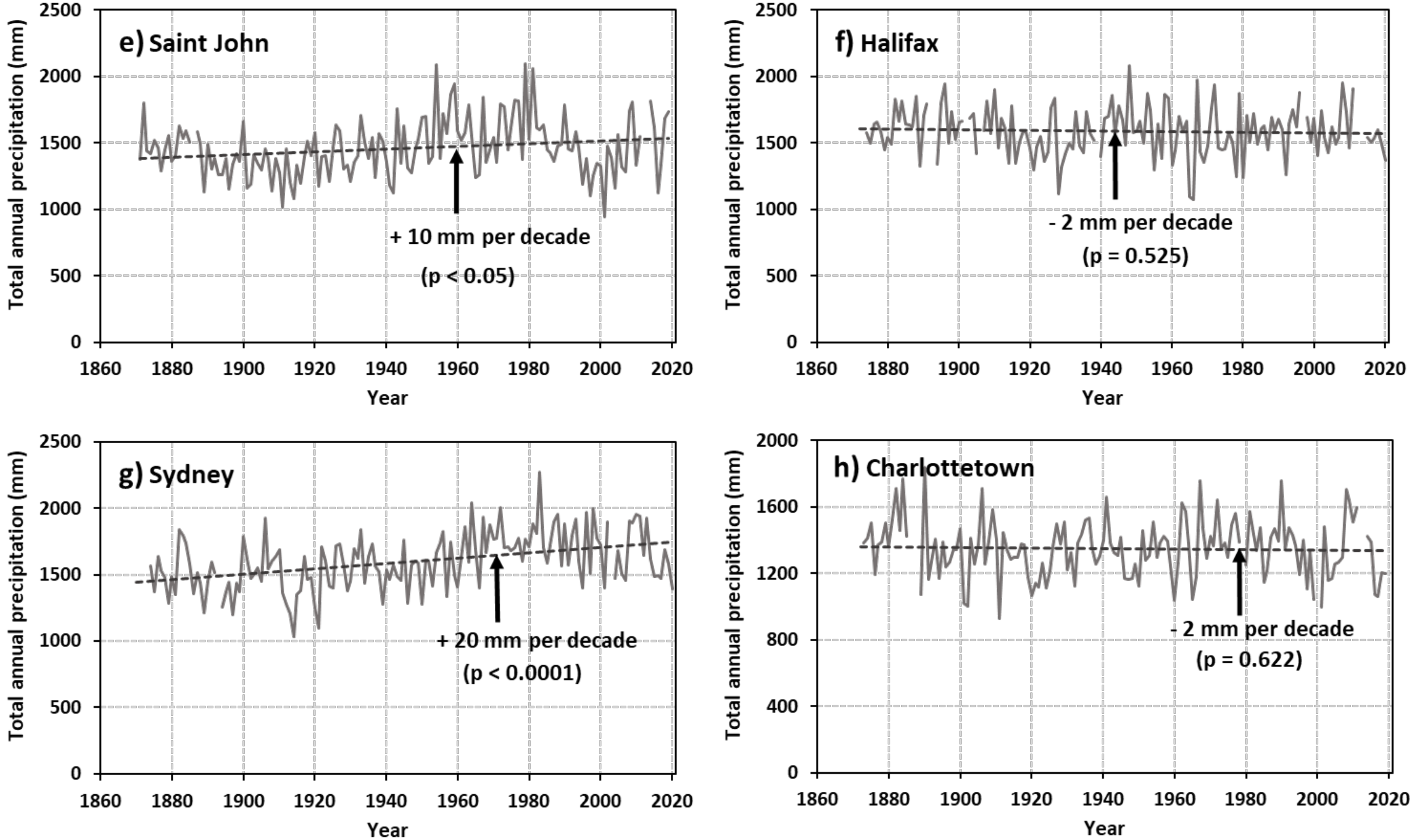

Figure 13 (Continued). Long-term total annual precipitation for selected stations in the Maritime provinces.

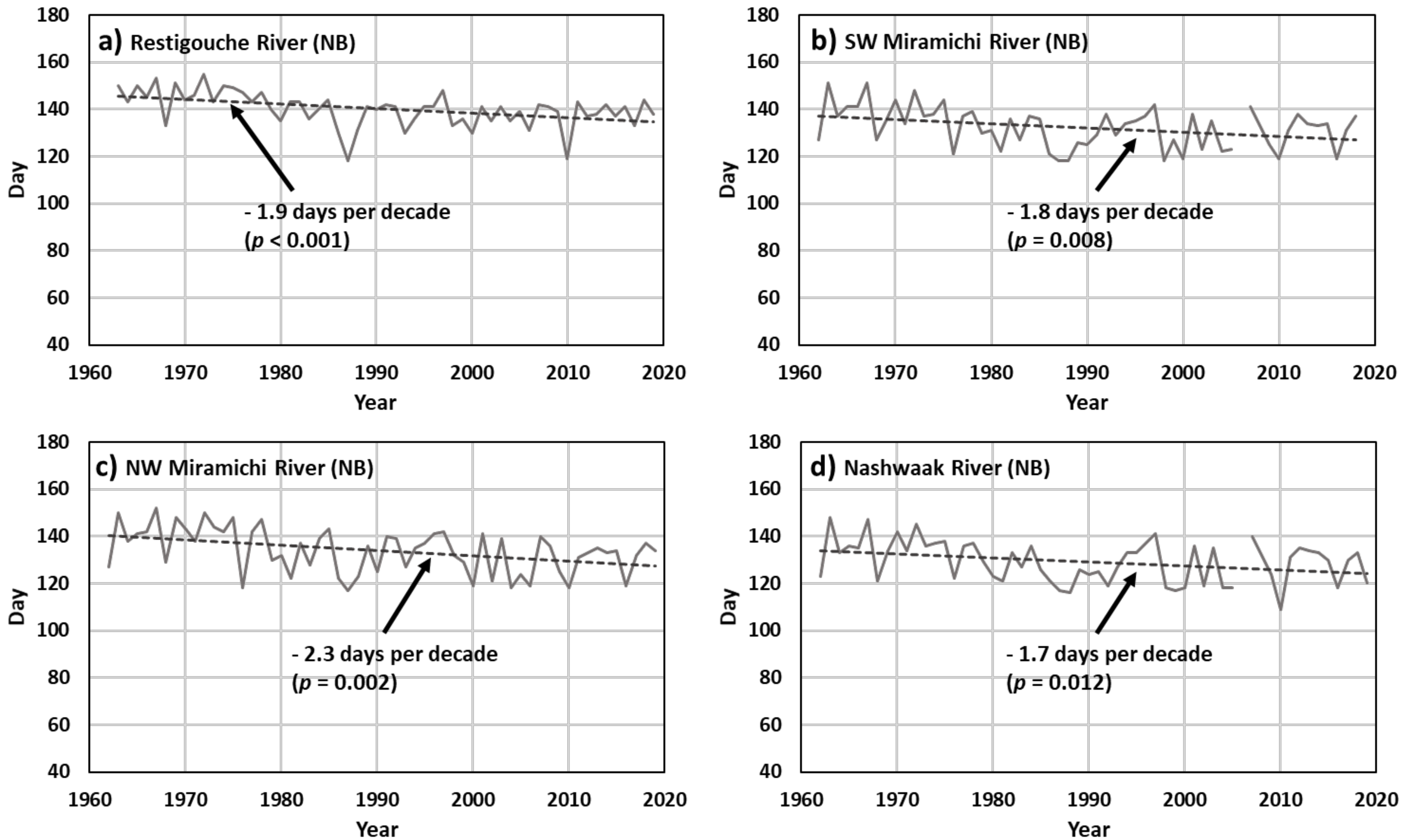

Figure 14. 30-day moving average spring high flow date for selected rivers in the Maritime provinces.

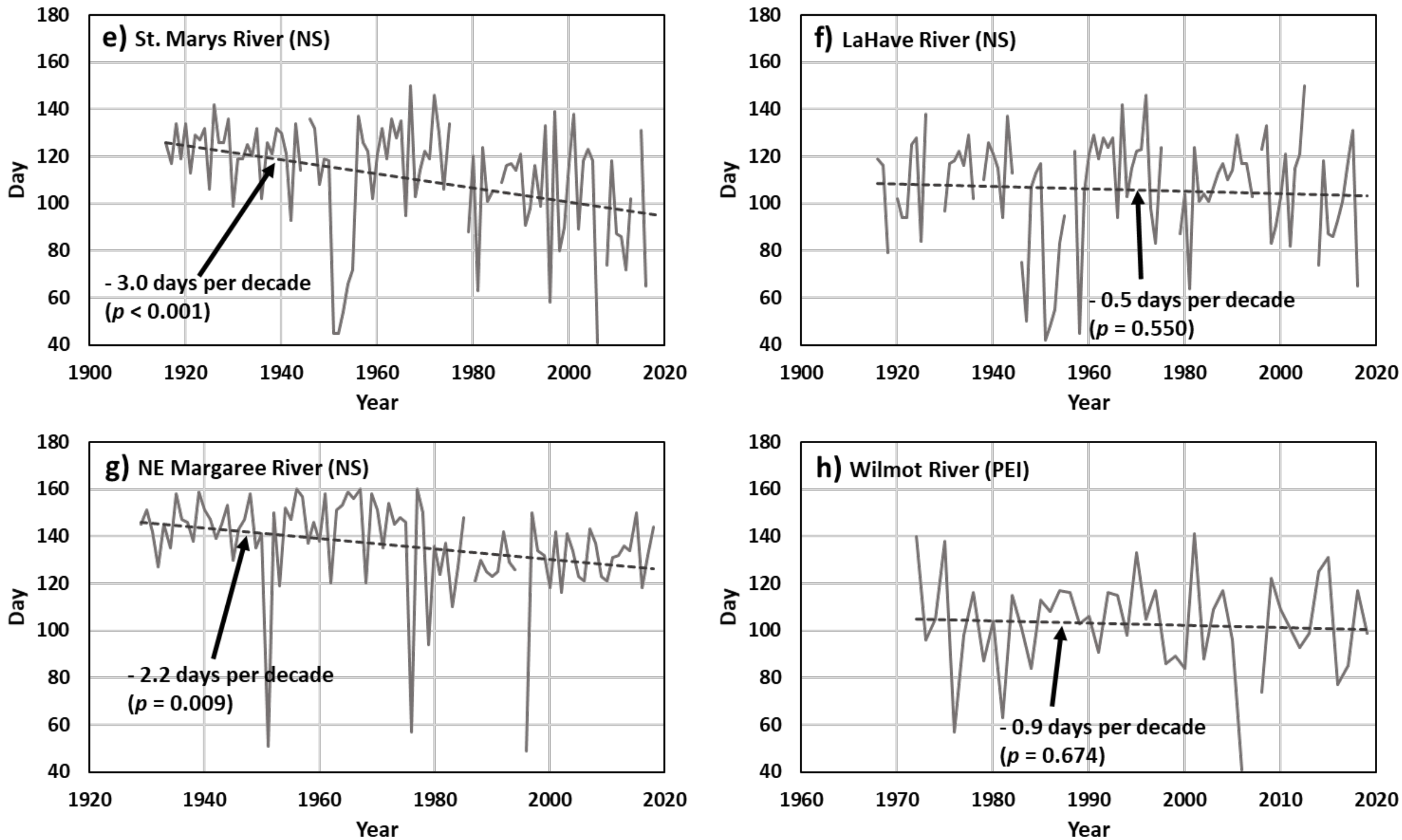

Figure 14 (Continued). 30-day moving average spring high flow date for selected rivers in the Maritime provinces.

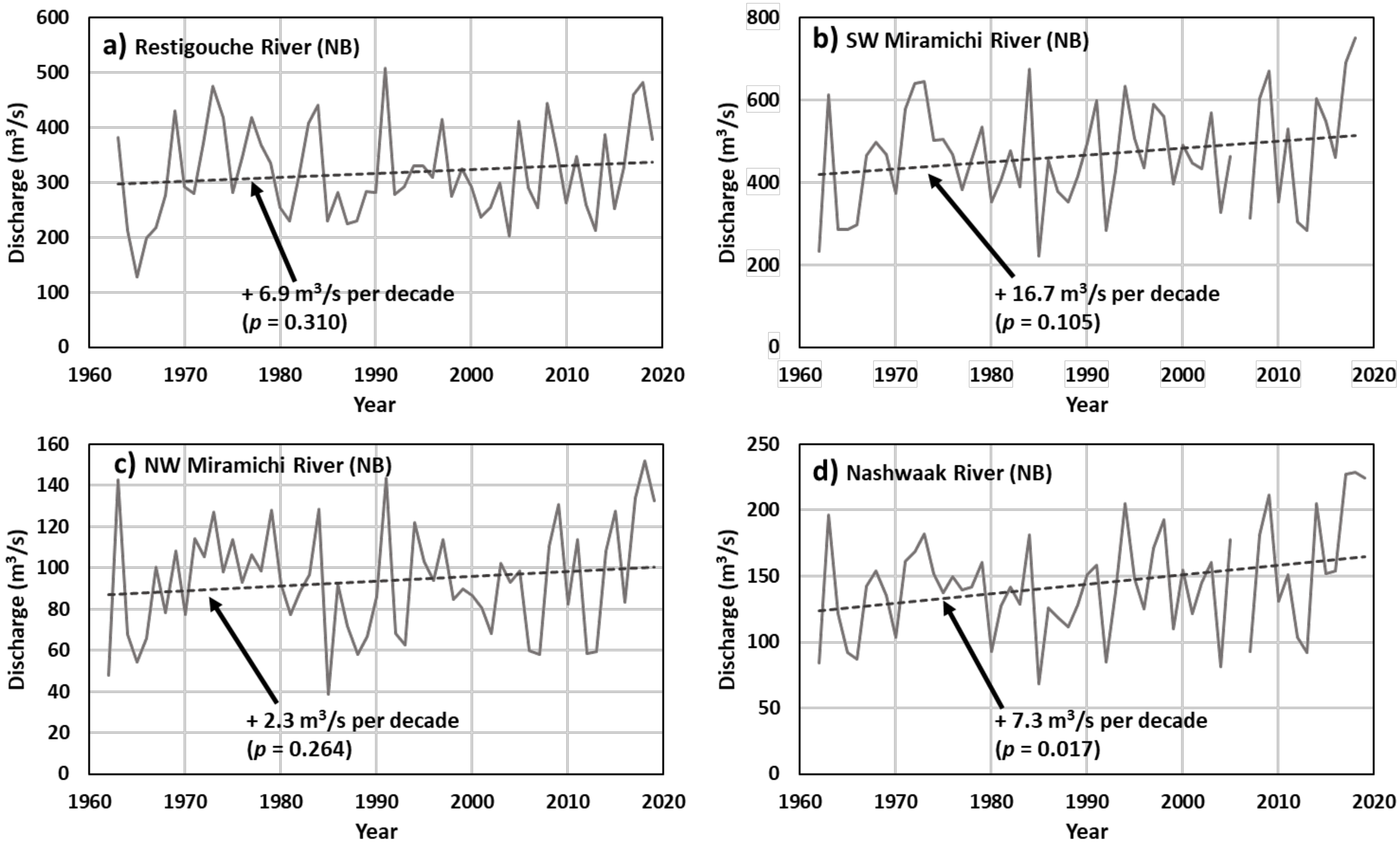

Figure 15. 30-day moving average spring high flow magnitude for selected rivers in the Maritime provinces.

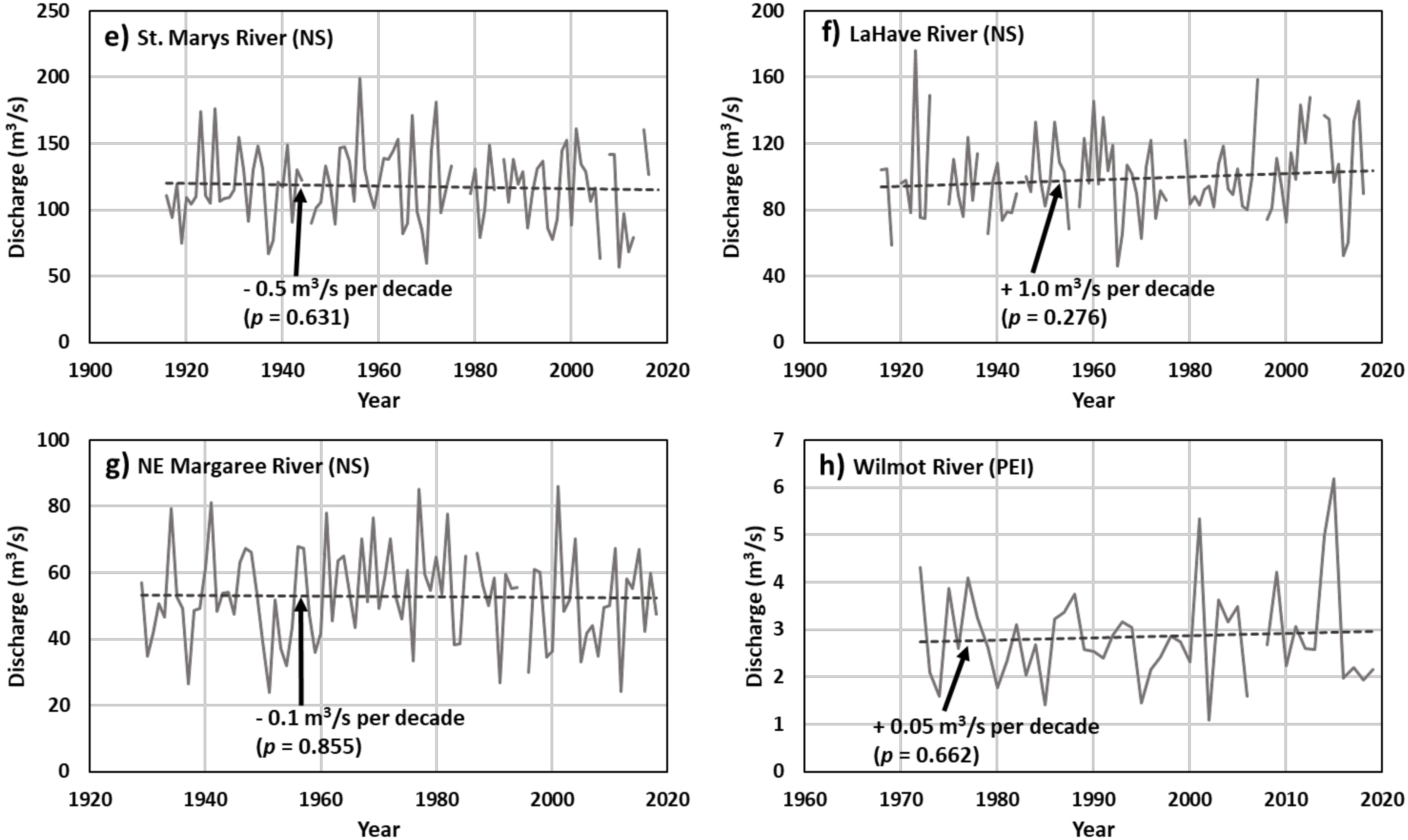

Figure 15 (Continued). 30-day moving average spring high flow magnitude for selected rivers in the Maritime provinces.

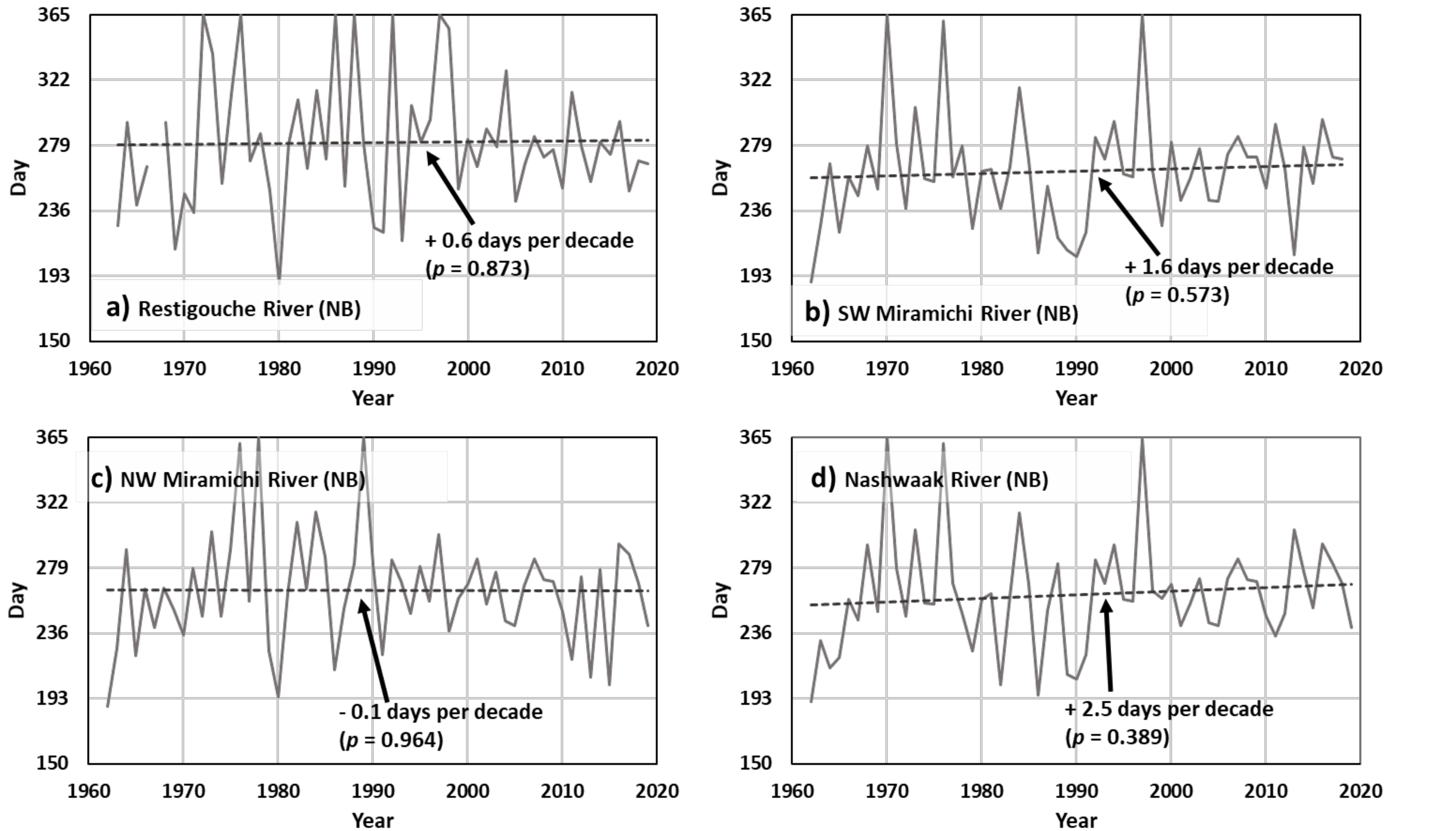

Figure 16. 30-day moving average summer low flow date for selected rivers in the Maritime provinces.

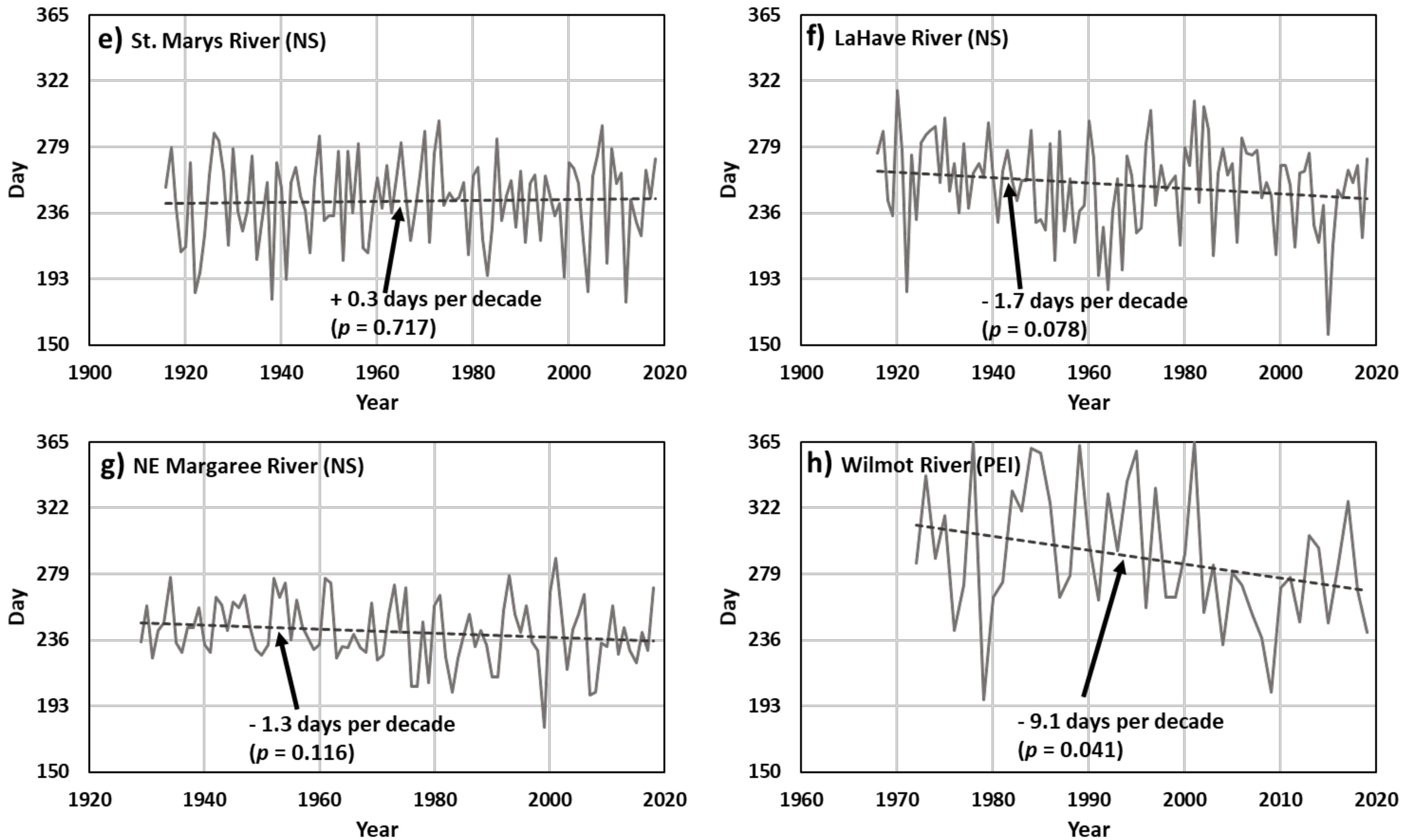

Figure 16 (Continued). 30-day moving average summer low flow date for selected rivers in the Maritime provinces.

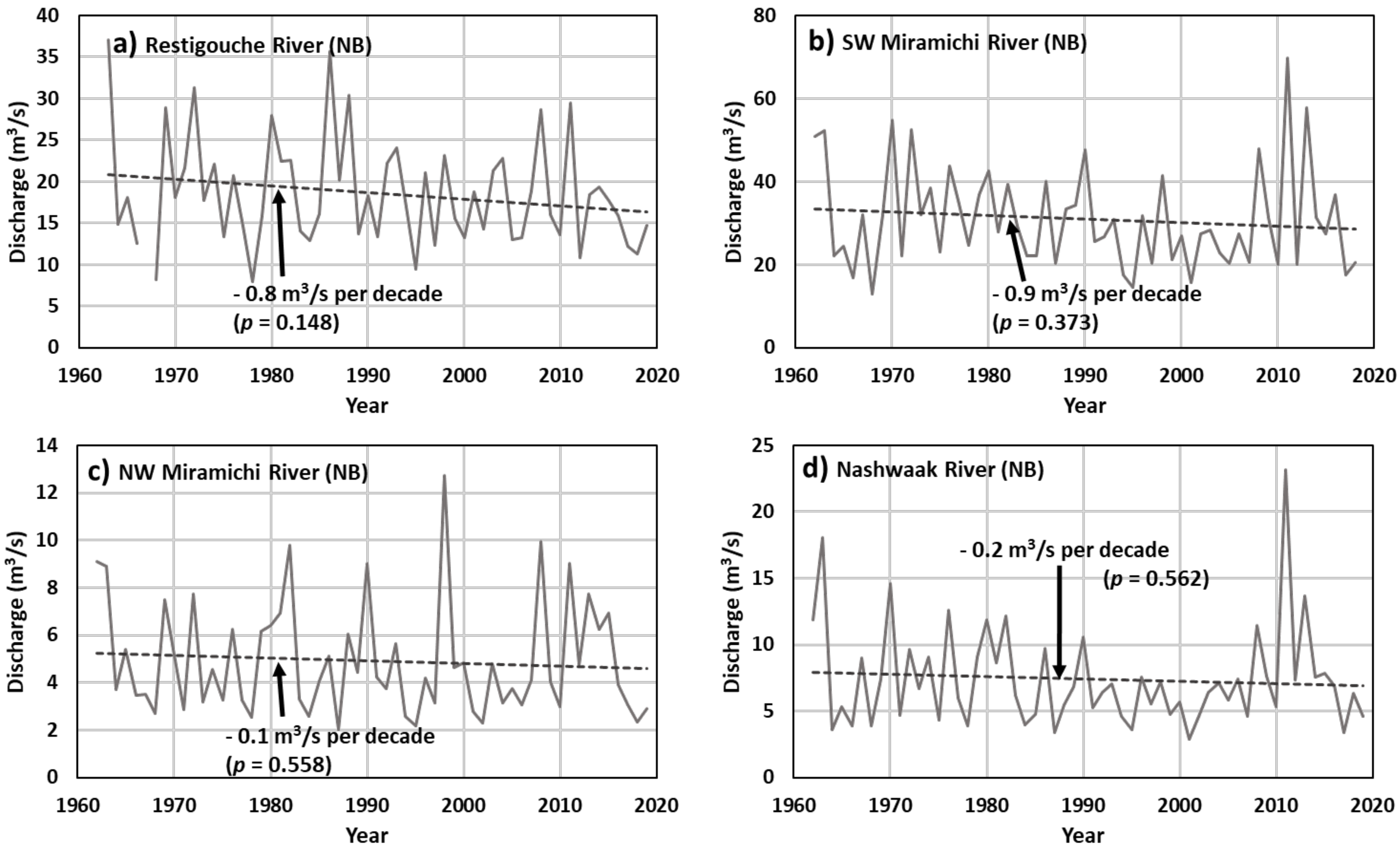

Figure 17. 30-day moving average summer low flow magnitude for selected rivers in the Maritime provinces.

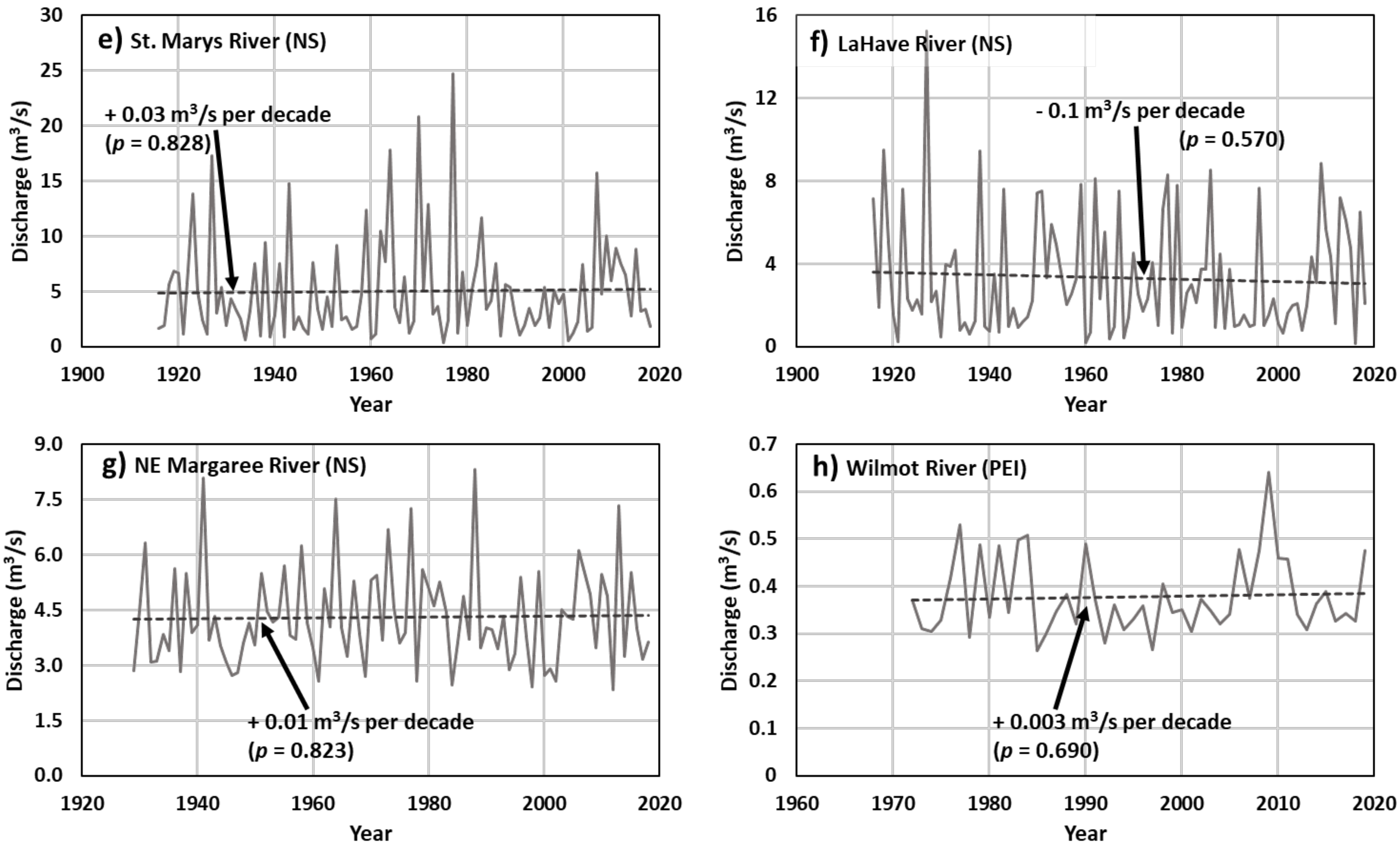

Figure 17 (Continued). 30-day moving average summer low flow magnitude for selected rivers in the Maritime provinces.

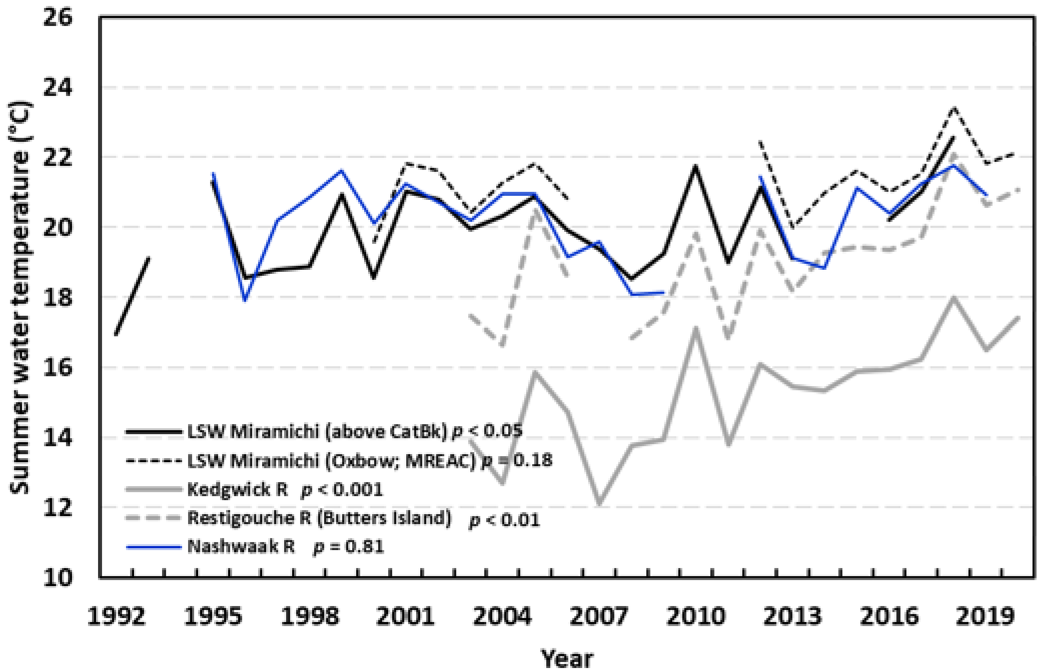

Figure 18. Results of mean summer (July-August) river temperatures at selected sites within the Maritime provinces and associated trends between 1992 and 2020.