Tobique River water temperatures and hydrometeorological data collected over the past two decades

G. Goguen, D. Caissie, N. El-Jabi and R.A. Jones

Fisheries and Oceans Canada
Gulf Region / Maritime Region
Science Branch
343 Université Avenue
Moncton, NB
E1C 9B6

2018

Canadian Data Report of Fisheries and Aquatic Sciences 1285

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Canadian Data Report of Fisheries and Aquatic Sciences

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By

Gabriel Goguen[1], Daniel Caissie[2], Nassir El-Jabi[1] and Ross A. Jones[3]

Fisheries and Oceans Canada
Gulf Region[2]
Maritimes Region[3]
Science Branch
343 Université Avenue
Moncton, NB
E1C9B6

[1.] Université de Moncton, Moncton, New Brunswick

Cat. Fs97-13/1285E-PDF ISBN 978-0-660-26779-1 ISSN 1488-5395

Correct citation for this publication:

Goguen, G., D. Caissie, N. El-Jabi, R.A. Jones. 2018. Tobique River water temperatures and hydrometeorological data collected over the past two decades. Can. Data Rep. Fish. Aquat. Sci. 1285: viii + 67p.

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Goguen, G., D. Caissie, N. El-Jabi, R.A. Jones. 2018. Tobique River water temperatures and hydrometeorological data collected over the past two decades. Can. Data Rep. Fish. Aquat. Sci. 1285: viii + 67p.

The Tobique River (New Brunswick) and its tributaries have important salmon populations and this river also has an important network of dams and reservoirs that are used for hydroelectric production purposes. These hydraulic structures can have some influences or impacts on fisheries and aquatic resources. For instance, studies have shown that the regulation of streams and rivers can impact flow regimes as well as water temperatures downstream of dams. The objectives of the present report are to present data on air temperature, discharge as well as water temperature at different sites to have a better understanding on potential relationships between flow regulation downstream of dams and reservoirs and the variation of temperature regimes within the watershed. The water temperature data from the Gulquac River (South Branch) was used as a control as it is a natural system not influenced by dams and reservoirs. It was noted that within the Tobique system, five sites showed higher mean summer water temperatures than at the Gulquac River, whilst two sites showed lower mean summer water temperatures. During winter months, the Sisson Branch showed the highest monthly mean river temperatures in the range of 1.3°C-1.5°C (from January to March). River Dee, River Don and Campbell River also recorded mean daily winter temperatures greater than 0°C during several sporadic events. Such events were observed in 2002; however, are also present during other years during the winter period. As most sites were relatively close geographically and significant differences in water temperatures were present, it is clear that factors other than location impacted water temperatures.

RÉSUMÉ

Goguen, G., D. Caissie, N. El-Jabi, R.A. Jones. 2018. Tobique River water temperatures and hydrometeorological data collected over the past two decades. Can. Data Rep. Fish. Aquat. Sci. 1285: viii + 67p.

La rivière Tobique (Nouveau-Brunswick) et ses affluents ont d'importantes populations de saumon, et cette rivière possède également un important réseau de barrages et réservoirs qui sont utilisés à des fins de production hydroélectrique. Ces structures hydrauliques peuvent avoir certaines influences ou impacts sur la pêche et les ressources aquatiques. Par exemple, des études ont montré que la régulation des cours d'eau peut avoir un impact sur le régime d'écoulement ainsi que sur les températures de l'eau en aval des barrages. Les objectifs du présent rapport sont de présenter des données sur la température de l'air, les débits et la température de l'eau à différents sites afin de mieux comprendre les relations potentielles entre la régulation du débit en aval des barrages (réservoirs) et la variation de la température dans le bassin versant. La rivière Gulquac (branche sud) a été utilisée comme site de contrôle car elle est un système naturel non influencé par les barrages et les réservoirs. Il a été noté qu'au niveau de la rivière Tobique, cinq sites affichaient des températures moyennes d'eau estivales plus élevées que celles de la rivière Gulquac tandis que deux sites affichaient des températures moyennes d'eau estivale inférieure au site de contrôle. Pendant les mois d'hiver, le site Sisson Branch a démontré des températures de rivière plus élevées et d'environ 1.3°C – 1.5°C (de janvier à mars). La rivière Dee, rivière Don et la rivière Campbell ont également montré des températures hivernales au-dessus de zéro pendant plusieurs événements sporadiques. De tels événements ont été observés en 2002; cependant, ils étaient aussi présents pendant d'autres années. Comme la plupart des sites étaient relativement proches géographiquement et que des différences significatives dans la température de l'eau étaient présentes, il est clair que des facteurs autres que l'emplacement des sites ont contribué à cette différence de température de l'eau.

1. INTRODUCTION

Dams and reservoirs are widespread throughout the world and these hydraulic structures are used for a variety of purposes, e.g., irrigation, water supply, hydroelectric, etc. These hydraulic structures can have some influences or impacts on fisheries and aquatic resources. For instance, studies have shown that the regulation of streams and rivers can impact flow regimes as well as water temperatures downstream of dams and reservoirs (Poff et al. 1997; Olden and Naiman 2010; McLaughlin et al. 2014). Many aquatic species are highly sensitive to flow and water temperature variability and, any modifications to the thermal regime will ultimately influence metabolic and growth rates, distribution and general physiology of fish within river systems. Salmonids are particularly sensitive to water temperature fluctuations and are especially vulnerable to high temperature events (Huntsman 1942; Lee and Rinne 1980; Breau et al. 2011; DFO 2012). In the past few decades, the salmon population has decreased significantly within the Outer Bay of Fundy (OBoF) region and more specifically on the Saint John River above the Mactaquac Dam (DFO 2014; Jones et al. 2014). Such decline in the OBoF salmon population has been attributed to a variety of factors including negative impacts from the presence and the operation of dams and reservoirs, e.g., turbine mortality (Clarke et al. 2014; DFO 2014). The Tobique River (New Brunswick) and its tributaries have important salmon populations (Jones et al. 2014), and this river also has an important network of dams and reservoirs that are used for hydroelectric production purposes (Marshall et al. 2014). Although the present data report does not provide salmon related data, the hydrometeorological data presented are key parameters for salmon populations. Therefore, the objectives of the present report are to present data on air temperature, discharge as well as water temperature at different sites in the upper Saint John River to have a better understanding on potential relationships between flow regulation downstream of dams and reservoirs and the variation of temperature regimes within the watershed.

2. MATERIALS AND METHODS

2.1 Study sites

The study area monitored for water temperatures consists of eight sites within the Tobique River watershed (Lat: 47° 10' 01" N, Long: 67° 05' 23" W; Figure 1) and one site within the

Shikatehawk Stream watershed (Lat: 46° 29' 15" N, Long: 67° 27' 14" W; Figure 1). The total catchment area of the Tobique River is 4331 km^2 while the Shikatehawk Stream has a drainage area of 201 km^2. The headwaters of the Tobique River are near Nictau (New Brunswick) and the river length is approximately 107 km, reaching its confluence with the Saint John River between the communities of Aroostook and Perth-Andover. There are four storage lakes within the Tobique River watershed, which include (from the smallest to largest in surface area): Serpentine Lake (5.1 km^2), Long Lake (10.2 km^2), Trousers Lake (10.9 km^2) and the Sisson Branch Reservoir (16.0 km^2).

Of the eight sites monitored for river water temperatures within the Tobique River system, six study sites were located on tributaries and two sites were located on the main stem (Figure 1). Namely, the tributary sites are located on the Gulquac River (South Branch) (non-regulated site), River Dee, River Don, Campbell River, Serpentine River and Sisson Branch. The two sites located on the main stem of the Tobique River are the Tobique River Fishway Trap (approximately 2 km from mouth of river) and the Tobique River Arthurette Bridge (approximately 22 km from mouth of river) sites. One additional non-regulated site monitored for water temperature was located outside of the Tobique River watershed and this site was on the Shikatehawk Stream (Figure 1). Table 1 presents the site names, location and upstream storage lakes or reservoirs as well as storage lake surface area. Five sites are downstream of storage reservoirs, namely the Sisson Branch, Serpentine River, Campbell River, River Dee and River Don (at a distance between 10-28 km from the reservoir), whereas two sites were much further downstream (Tobique River Fishway Trap and Tobique River Arthurette Bridge; Figure 1). The remaining two sites (i.e., Shikatehawk Stream and Gulquac River) are not affected by a storage reservoir, and as such, were used to monitor water temperature under natural conditions.

2.2 Data collection and manipulation

2.2.1 Air temperature

Air temperature data were gathered from the Government of Canada's Historical Data for two weather stations near the Tobique River watershed, namely the Aroostook and St. Leonard stations. The Aroostook weather station was located southwest of the Tobique River watershed and the St. Leonard weather station was located west of the Tobique River watershed (Figure 1).

Both stations presented similar proximity to the Tobique River. Data were available on a daily time scale. Both weather stations had missing data during the study time period (1995-2016); however, the St. Leonard station had the most complete data with only a few months of missing data. Daily mean values and monthly mean values were calculated from the available data.

2.2.2 Discharge

Discharge data were gathered from the Water Office of the Government of Canada's Historical Data for the Tobique River at the Riley Brook gauging station (01AH002) from 1995 to 2013. This was the only gauging station within the watershed with available data for the study period. The drainage area above this gauging station is 2230 km^2; approximately half of the total catchment area of the Tobique River. Data were available for daily mean and various statistics were then calculated from these values (i.e., overall means) for the study period.

2.2.3 Water temperature

Hourly water temperature readings were recorded using Vemco minilog thermometers (Vemco Inc., Bedford, Nova Scotia, Canada, vemco.com) model TR that were secured inside a PVC pipe for protection (Figure 2). Vemco minilog model TRs (-5 to +35 °C; accuracy ± 0.2 °C) were used to collect the majority of the data up until 2013 and more recently the Vemco minilog II (-5 to +35 °C; accuracy ± 0.1 °C) have been used. The minilogs/PVC pipe was secured to large instream boulder or nearby tree using a strong cable. Water temperature data presented in this report were collected at the 9 sites described above between 1995 and 2016. The Gulquac River (South Branch) site had the most months of data (172 months equivalent to 14.3 years; including only months with more than 29 days of data) while the Sisson Branch site had the lowest number of months of data (84 months equivalent to 7 years). The average number of months of data was 112 or 9.3 years.

3. DATA SUMMARY

3.1 Air temperature

Figure 3a presents the air temperature regime as well as the overall daily mean temperature at Aroostook weather station between 1995 and 2016. In this figure, the darker line

(black) represents the overall mean for each day of the year (i.e., mean of January 1, 2, etc.) whereas the grey lines represent the daily mean air temperature values for each year of data. As such, this figure informs on the overall air temperature regime as well as the air temperature variability during different times of year. The mean summer temperature (July and August) was 18.8°C at the Aroostook weather station (Table 2).

Figure 3b presents the air temperature regime as well as the overall daily mean temperature at the St. Leonard weather station (1995-2016). It was noted that air temperatures at St. Leonard were slightly lower than those monitored for Aroostook. For example, the summer (mean of July and August) air temperature at St. Leonard was 17.7°C, which is 1.1°C less than Aroostook (Table 2). It was noted that Aroostook had higher air temperatures (mean annual = 5.0°C) than St. Leonard (mean annual = 3.9°C), which represents a difference of 1.1°C (Table 2). January was the coldest month of the year for both stations with temperatures of -11.3°C (Aroostook) and -12.1°C (St. Leonard) while the warmest month was July (19.4°C at Aroostook vs. 18.2°C at St. Leonard). Table 3 presents the monthly mean air temperature by year for both Aroostook and St. Leonard from 1995 to 2016. The highest monthly mean air temperature at Aroostook was 20.6°C in August 2009, while at St. Leonard the mean was 19.7°C on two occasions in July (2006 and 2010). The lowest monthly mean air temperature was in February 2015 for both weather stations (-17.9°C at Aroostook and -17.3°C at St. Leonard).

3.2 Discharge data

Figure 4 presents the discharge data for the Tobique River at the Riley Brook hydrometric station from 1995 to 2013. The Riley Brook hydrometric station is located about 5 km downstream of the confluence of the headwater watersheds (Sisson Branch, Serpentine and Campbell rivers; Figure 1) and has a drainage area of 2230 km^2. In Figure 4, daily discharge data are present for each year as well as the overall mean daily value calculated for each day of year (presented by the dark black line, i.e., mean of January 1, 2, etc.). The overall mean discharge or mean annual flow was calculated at 51.9 m^3/s; however, flows were as high as 382 m^3/s and as low as 6.5 m^3/s during the study period (1995-2013; Figure 4). No trends in mean annual discharge were noted over the time period of 1995 to 2013 (p = 0.34). Table 4 presents mean monthly discharge on a yearly basis from 1995 to 2013 as well as yearly mean discharge (1995-

2013) and overall mean monthly discharge. It was noted that the highest mean monthly discharge was 202 m^3/s in May 1997 while the lowest mean monthly discharge was 9.2 m^3/s in September 1995. The highest mean yearly discharge was 71.1 m^3/s in 2008 while the lowest was 36 m^3/s in 2001. The months with the highest overall mean discharge were May and April (99.4 m^3/s in May and 92.4 m^3/s in April), which coincides with the melting of snow in spring. September was the month with the lowest overall mean monthly discharge at 29.9 m^3/s, but very close to August (32.9 m^3/s) and October (30.6 m^3/s).

3.3 Water temperature

Table 5 presents the monthly mean water temperatures at each site as well as summer mean temperatures (July and August) and the number of months considered in the calculations (i.e., including only months with more than 29 days of data). This table shows that the mean monthly water temperature values during the winter months (January – March) were generally close to 0°C, with the exception of the Sisson Branch, Serpentine River, River Dee, River Don and Campbell River which showed temperatures greater than 0 °C in winter. The Sisson Branch showed the highest monthly mean temperatures between 1.3°C and 1.5°C over the winter period. Highest mean monthly temperatures were generally observed in July and August when both of these months showed similar river temperatures. The site with the highest recorded monthly mean water temperature was the Tobique River Fishway Trap with a mean temperature of 21.3°C (July) and 21.4°C (August), although the mean temperature at the Tobique River Arthurette Bridge site was also very close (20.2°C; July). Summer mean temperatures (July and August) for these two sites were 21.3°C (Tobique River Fishway Trap) and 20.0°C (Tobique River Arthurette Bridge), respectively. Most other sites showed summer mean temperatures below 20°C (Table 3). Some sites showed relatively cooler (< 17 °C) summer mean temperatures at 16.0°C (Serpentine River), 16.4°C (Shikatehawk Stream) and 16.6°C (Sisson Branch). Notably, the summer temperatures for the Sisson Branch site were calculated with only 4 years of data.

Figures 5 and 6 show the water temperature regime (mean overall for each day of the year) at each study site in comparison with the thermal regime for the Gulquac River. The Gulquac River site was selected as a control site as it represents natural water temperatures without the influence of storage reservoirs (non-regulated). The overall mean water temperatures at the

Gulquac River site ranged from 0°C (winter) to 18.8°C (day 204; July 22), while the average length of winter period (i.e., with daily mean water temperatures < 0.25°C) was 118 days. The mean diel water temperature variability (maximum-minimum, daily basis) was 2.3°C whereas the maximum diel water temperature variability was 13.3°C.

Figures 5a and 5b show that overall mean water temperatures at the Tobique River Fishway Trap site and the Tobique River Arthurette Bridge presented similar patterns, with temperatures higher than the Gulquac River site. Temperatures at these sites were higher during spring, summer and autumn seasons; however, daily variability was higher at the Tobique River Arthurette Bridge site. The overall average water temperature diel variability at Tobique River Fishway Trap was 0.7°C (lowest among all sites) with a maximum diel variability of 6.5°C whilst overall average diel variability at Tobique River Arthurette Bridge was 2.0°C with a maximum diel variability of 8.7°C.

Figure 5c shows the overall mean water temperatures at Sisson Branch, where this site showed mean daily temperatures greater than 0°C during the winter months. The overall daily mean water temperature between January 1 and March 31 was 1.4°C (Table 3). It was also observed that overall mean temperatures were slightly lower at Sisson Branch than at Gulquac River for part of summer months followed by similar temperatures between day 240 (August 28) and day 325 (November 21) and higher temperatures during the month of December. Figure 5d shows that overall daily mean water temperatures at the Serpentine River site had a slightly earlier warming than Gulquac River; however, cooler temperatures were observed between day 120 (April 30) and day 250 (September. 7) at Serpentine River site. Water temperatures were similar to those at Gulquac River for autumn and winter months but slightly cooler between day 280 (October 7) to day 325 (November 21).

Figures 6a, 6b and 6c show the overall daily mean water temperatures at the regulated sites on the River Dee, River Don and Campbell River sites where Figure 6d show temperatures at the unregulated site on the Shikatehawk Stream. The River Dee, River Don and Campbell River showed warmer daily mean temperatures (than the Gulquac River) in later winter (between days 75 and 125; March 16 and May 5); however, these sites had similar temperatures to the

Gulquac River during the rest of the year. Figure 6d shows that overall daily mean water temperatures at the Shikatehawk Stream site were similar to those at Gulquac River during autumn and winter with the exception that an earlier warming was observed at the Shikatehawk Stream site during the spring season. The overall daily mean summer temperatures were also slightly lower at Shikatehawk Stream when compared to Gulquac River during the summer peak temperatures (between day 160 and 230; June 9 and August 18).

Figures 7 and 8 show the daily mean water temperatures for 2002 at each study site in comparison with the Gulquac River site. Figures for all other years (1995-2016, excluding 2002) are presented in Appendix A. Figure 7a and 7b show that daily mean water temperatures in 2002 at the Tobique River Fishway Trap site and the Tobique River Arthurette Bridge sites were higher during spring, summer and autumn than at the Gulquac River site. Daily variability was higher at the Tobique River Arthurette Bridge site than at the Tobique River Fishway Trap site. The average water temperature variability at the Tobique River Arthurette Bridge from day 116 (April 26) to 319 (November 15) in 2002 (time period with comparative data) was 3.1°C with a maximum variability of 7.3°C. The average water temperature variability for the same period at Tobique River Fishway Trap was 1.0°C with a maximum water temperature variability of 3.4°C. Mean daily water temperatures exceeded 25°C from day 184 (July 3) to day 185 (July 4) and from day 226 (August 14) to day 230 (August 18) at the Tobique River Arthurette Bridge sites. As for the Tobique River Fishway Trap site, mean daily water temperatures exceeded 25°C from day 228 (August 16) to day 233 (August 21).

Figure 7c shows that daily mean water temperatures rarely reached 0°C at the Sisson Branch site over the winter period of 2002. Temperatures were above 0.25°C for 74 days between January 1 and March 31 and the average temperature was 1.5°C during this period. Daily mean temperatures in 2002 were higher in early summer and lower in late summer than those at the Gulquac River site. Figure 7d shows that daily mean temperatures at the Serpentine River site had a slightly earlier warming than Gulquac River in 2002, followed by colder temperatures until late summer. Water temperatures were similar to those at Gulquac River in autumn and winter with the exception of a few days in December.

Figures 8a, 8b and 8c show that daily mean water temperatures were slightly higher at the River Dee, River Don and Campbell River sites than at the Gulquac River site during the winter and early spring of 2002. River Dee and Campbell River registered mean daily water temperatures above 0°C during winter months on several occasions (Figure 8a; Figure 8c). For example, using the above threshold of 0.25°C, River Dee showed 47 days with mean daily temperature above this value in 2002 (between January 1 and March 31). Similarly, water temperature at the Campbell River showed 30 days with mean daily temperature above 0.25°C during the same period. As for River Don, daily mean temperatures in 2002 were close to 0°C until approximately day 55 but remained above 0°C the remainder of the winter and spring period (total of 32 days; Figure 8b). Figure 8d shows the daily mean temperatures in 2002 at the Shikatehawk Stream site compared to temperatures at Gulquac River. During autumn and winter, temperatures were similar among these two sites with the exception that an earlier warming was present at the Shikatehawk Stream. It was also noted that Shikatehawk Stream had warmer temperatures during spring and cooler temperatures during summer when compared to Gulquac River. In 2002, the spring warm up (daily mean > 0.25 °C) occurred 15 days earlier than on the Gulquac River.

4. CONCLUSIONS

This report presents data on air temperatures, river discharge and water temperatures within the Tobique River system (New Brunswick), where a number of sites are influenced by upstream dams and reservoirs. The Gulquac River (South Branch) was used as a control site as it is a natural system not influenced by dams and reservoirs. It was noted that within the Tobique system that five sites showed higher mean summer water temperatures than at the Gulquac River, whilst two sites showed lower overall monthly mean summer water temperatures. During winter months, the Sisson Branch showed highest overall monthly mean river temperatures in the range of 1.3°C and 1.5°C (from January to March). River Dee, River Don and Campbell River also recorded daily mean winter temperatures greater than 0°C during several sporadic events. Such events were observed in 2002; however, are also present during other years. As most sites were relatively close geographically and significant differences in water temperatures were present, it

is clear that factors other than location impacted water temperatures during certain years of the study.

5. ACKNOWLEDGEMENTS

This study was funded through the Priorities and Partnership Fund Strategic Initiatives 2016-17. Minilog installation and maintenance, data downloads and data verification were made possible with the support of Fisheries and Oceans Canada technicians C. Fitzherbert and L. Anderson. Field support staff was often provided by Tobique First Nation and/or Tobique Salmon Protection Association. Authors also thank Sarah Tuziak and Wayne Fairchild for their comments on the manuscript.

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Table 1. Water temperature site location and characteristics

Station	Latitude	Longitude	Watershed	Upstream storage lake(s)	Storage lake area (km^2)	Distance to storage lake (km)
Tobique R. at Fishway Trap	46° 46' 46.6" N	67° 41' 41.1" W	Tobique River	Sisson, Trousers, Long, Serpentine	42.36[a]	
Tobique R. at Arthurette Bridge	46° 47' 49.1" N	67° 28' 51.4" W	Tobique River	Sisson, Trousers, Long, Serpentine	42.36[a]	
Sisson Branch	47° 14' 53.8" N	67° 09' 53.5" W	Tobique River	Sisson Branch Reservoir	16.04	10.0
Serpentine R.	47° 16' 21.4" N	66° 56' 02.8" W	Tobique River	Serpentine Lake	5.13	27.5
River Dee	47° 07' 24.8" N	67° 00' 23.3" W	Tobique River	Trousers Lake	10.91	15.7
River Don	47° 07' 30.8" N	66° 59' 59.4" W	Tobique River	Long Lake	10.28	12.5
Campbell R.	47° 08' 08.4" N	66° 59' 54.4" W	Tobique River	Long and Trousers	21.19[a]	13.9 (to Long) / 17.6 (to Trousers)
Shikatehawk Stream	46° 30' 06.4" N	67° 27' 07.4" W	Shikatehawk Stream	N/A		
Gulquac R. (South Branch)	46° 57' 43.9" N	67° 11' 08.0" W	Tobique River	N/A		

[a] Storage lake area (km^2) above these sites

Table 2. Monthly air temperatures (°C) and the number of years of data at the St. Leonard and Aroostook meteorological stations

	St Leonard		Aroostook		
	avg	n	avg	n	Difference[(1)]
January	-12.11	22	-11.34	16	-0.77
February	-10.65	22	-9.70	15	-0.96
March	-4.85	22	-3.77	16	-1.08
April	2.58	22	3.72	16	-1.14
May	10.21	22	11.29	16	-1.07
June	15.21	22	15.91	16	-0.70
July	18.22	21	19.38	16	-1.15
August	17.12	21	18.30	13	-1.18
September	12.72	22	14.07	18	-1.35
October	5.78	22	7.23	18	-1.45
November	-0.45	22	0.68	17	-1.13
December	-7.63	22	-6.16	16	-1.47
Mean[(2)]	3.85		4.97		-1.12

[(1)] Difference between St Leonard weather station and Aroostook weather station

[(2)] Mean value of monthly average

n : Number of years considered in average

Table 3. Mean monthly air temperature (^{o}C) by year (1995 – 2016) at Aroostook and St. Leonard meteorological stations

	January		February		March		April		May		June	
	Aroostook	**St Leonard**	**Aroostook**	**St Leonard**	**Aroostook**	**St Leonard**	**Aroostook**	**St Leonard**	**Aroostook**	**St Leonard**	**Aroostook**	**St Leonard**
1995	-9.1	-10.1	-13.6	-13.6	-3.3	-4.3	1.0	0.2	10.5	9.3	17.3	16.0
1996	-12.3	-12.5	-10.7	-11.2	-4.8	-5.5	4.4	3.0	9.1	8.3	17.5	15.8
1997	-11.5	-12.9	-10.7	-11.8	-7.8	-8.0	2.1	1.3	8.7	7.4	15.7	14.7
1998	-9.9	-10.8	-8.5	-6.8	-2.9	-3.1	4.6	3.8	13.8	13.0	15.7	15.7
1999	-11.9	-12.6	-8.0	-8.7	-0.6	-1.4	3.7	3.2	13.8	13.5	18.3	17.4
2000	-11.6	-12.3	-10.6	-10.1	-0.6	-1.5	3.7	2.0	10.0	8.8	15.4	13.9
2001	-11.8	-12.2	-11.2	-11.5	-5.2	-5.2	2.8	2.4	13.3	12.7	16.7	15.8
2002		-10.4		-9.6		-5.3		2.8		8.6		13.2
2003		-15.5		-14.6		-6.7	0.3	-0.5	9.7	9.1	16.3	15.6
2004	-16.2	-16.7	-9.9	-10.6	-3.5	-4.2	4.4	2.8	10.5	9.5	13.7	12.7
2005	-13.7	-15.3	-8.6	-9.0		-4.9		3.7		8.5		16.8
2006		-8.4		-11.0		-3.1		4.6		11.6		17.3
2007		-11.7		-13.2		-5.7		1.7		9.4		15.4
2008	-9.5	-10.7	-9.6	-11.0	-6.7	-8.3	5.2	4.2	9.8	9.1	16.2	15.3
2009	-15.7	-16.8	-7.8	-9.0	-4.1	-5.5	5.2	3.9	10.6	9.4	16.1	15.2
2010	-6.5	-7.5	-3.9	-5.0	0.6	-1.0	7.1	6.1	13.3	11.4	15.8	14.9
2011	-10.1	-10.8	-10.9	-11.6	-3.3	-5.4	3.0	1.6	11.3	10.0	15.7	14.9
2012	-9.5	-11.4	-8.5	-9.1	-0.1	-1.5	5.5	4.1	11.7	11.0	15.7	15.2
2013	-11.2	-12.2	-7.8	-9.0	-0.9	-1.8	3.9	2.4	11.9	11.1	14.5	14.3
2014	-11.1	-11.7	-11.2	-11.5	-9.4	-10.2	3.6	1.9	11.4	10.4	16.9	16.5
2015	-15.8	-14.3	-17.9	-17.3	-7.6	-7.8	2.5	1.5	12.7	11.9	14.0	13.1
2016	-7.8	-9.8	-7.1	-9.3		-6.4		0.3		10.6		14.9

Table 3. (Continued) Mean monthly air temperature (°C) by year (1995 – 2016) at Aroostook and St. Leonard meteorological stations

	July		August		September		October		November		December	
	Aroostook	**St Leonard**	**Aroostook**	**St Leonard**	**Aroostook**	**St Leonard**	**Aroostook**	**St Leonard**	**Aroostook**	**St Leonard**	**Aroostook**	**St Leonard**
1995	20.5	19.4	18.4	17.3	12.8	10.0	10.1	7.9	-1.0	-3.1	-9.6	-10.6
1996	19.4	17.7	19.1	16.9	14.2	11.8	6.9	5.1	-1.1	-2.4	-2.1	-3.7
1997	19.0	17.7	16.2	15.3	12.6	11.8	5.8	4.4	-0.2	-2.1	-8.4	-9.4
1998	20.0	18.5	18.1	16.9	13.4	12.4	6.2	5.8	-0.9	-1.7	-5.1	-7.3
1999	20.3	18.6	17.2	16.5	16.9	16.2	5.2	4.1	1.8	0.9	-3.9	-6.3
2000	18.5	16.8	18.0	16.4	13.4	11.2	5.7	5.1	2.8	1.2	-9.5	-10.0
2001	18.5	17.8	19.5	18.1	14.6	13.4	8.2	3.3		1.3		-3.8
2002		17.3		17.8		13.4		3.9		-3.0		-9.1
2003	18.6	17.8	18.6	17.2	14.8	14.0	6.6	5.5	1.1	-0.4	-5.3	-6.2
2004	19.5	18.0	18.6	17.0	12.9	11.7	7.3	6.3	-0.3	-2.1	-8.7	-10.5
2005		18.1		17.6		12.7		7.7		-0.1		-8.5
2006		19.7		15.1		12.0		5.9		1.9		-5.5
2007	17.7	17.9	17.3	15.9	14.3	12.3	9.9	8.0	-0.3	-2.2	-9.4	-10.9
2008	19.9	19.2	18.1	17.0	13.9	13.0	7.1	5.7	2.1	0.6	-7.2	-10.0
2009	18.3	17.3	20.6	17.8	13.0	11.7	4.9	3.4	3.4	2.1	-6.1	-7.2
2010	20.3	19.7	19.3	17.7	14.6	13.1	7.2	5.9	0.8	-0.3	-3.8	-4.4
2011	19.7	18.1	18.6	17.5	14.8	13.4	8.9	7.1	4.7	2.4	-4.5	-6.6
2012	19.7	18.5	20.1	18.8	14.1	12.7	8.5	7.4	0.3	-1.3	-4.5	-6.7
2013	19.5	18.6	17.0	16.3	13.5	12.6	7.9	6.7	-0.3	-1.5	-9.4	-11.8
2014	20.3	19.2	18.9	17.9	13.7	12.3	8.3	7.5	-1.0	-2.2	-5.2	-6.4
2015	18.4	16.8	20.5	18.9	16.3	15.0	6.0	4.0	2.0	0.8	-1.3	-3.2
2016		16.7			14.2	13.3	7.7	6.7	2.2	1.3	-7.9	-9.9

Table 4. Mean monthly discharge (m^3/s) by year (1995 – 2013) at the Riley Brook gauging station on Tobique River

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1995	61.5	48.4	46.5	78.7	145	44.1	19.3	12.8	9.21	13.5	35.5	28.5	45.2
1996	57.7	46.2	68.1	87.2	90.9	36.3	30.4	23.1	19.3	23.7	69	61.4	51.1
1997	53	51.4	51.6	58.6	202	63.6	41.8	18.7	18.6	15.4	15.7	15.8	50.6
1998	15.1	26.7	91.1	148	79	51.1	77.7	29.8	35.9	46.5	48	38.1	57.4
1999	64	83	48.1	95.2	92.4	25	15.2	16.4	48.4	56.3	66.9	75.4	57
2000	41.1	48.2	60	146	113	37.3	27	22.8	22.4	23.8	36.6	36.6	51.1
2001	59.8	46.9	33.9	56.1	83.8	37.6	24.5	13.4	12.8	13.7	20.6	29.3	36
2002	44.1	54.8	38.7	95.1	80.9	28.9	35	26.6	22.3	19.4	23.7	36.8	42.1
2003	29.6	42.2	33.9	94.8	118	44.4	30.9	50.8	19.7	35.2	88.3	68.4	54.7
2004	57.7	49.4	30.1	60.2	62.1	24	20.5	23.6	32.9	19.9	19.1	46.1	37.1
2005	70.5	61.3	40.9	108	99.9	44	21.8	13.7	24	52.9	107	114	63.1
2006	114	74.8	61.6	97.6	83.3	39.8	20.5	21.4	11.1	20.5	82.2	49.4	56.2
2007	51.6	52.6	37.2	59.5	81.1	34.4	34.7	33	20.5	18.4	65.9	38.3	43.8
2008	67.6	60.5	51.6	115	146	57.8	49.4	72.1	33.6	46.4	72.8	79.7	71.1
2009	58.3	48.4	39.6	130	111	58.5	34.8	38.9	13.9	29.1	53.9	52.1	55.7
2010	36.1	44.7	33.7	112	46.4	31.6	60.8	29	15.4	33.5	57.5	111	51
2011	60.5	55	77	88.1	123	62.5	57.4	88.7	60.4	33.1	27.3	34.8	64.1
2012	42	44.8	63.5	77.6	63.5	33.6	33.1	37.3	32	24.3	20.2	19.6	40.9
2013	37.3	64.2	35.5	48.4	67.7	74.1	33	53.3	116	55.2	46.9	59	57.4
Mean	53.8	52.8	49.6	92.4	99.4	43.6	35.1	32.9	29.9	30.6	50.4	52.3	51.9

Table 5. Monthly water temperatures (°C) and the number of years of data for the Tobique River study sites as well as river temperatures for the Shikatehawk Stream (1995-2016)

	Tobique R. at Fishway Trap		Tobique R. at Arthurette Bridge		Sisson Branch		Serpentine R.		River Dee		River Don		Campbell R.		Shikatehawk Stream		Gulquac R. (South Branch)	
	Avg	n	Avg	n	Avg	n	Avg	n	Avg	n	Avg	n	Avg	n	Avg	n	Avg	n
Jan	0.1	5	0.0	9	1.3	10	0.1	14	0.1	13	0.0	14	0.1	12	0.1	14	0.0	15
Feb	0.0	5	0.0	9	1.5	10	0.1	14	0.2	13	0.0	14	0.1	12	0.0	14	0.0	15
Mar	0.1	4	0.0	9	1.4	6	0.2	12	0.7	12	0.5	13	0.6	12	0.2	13	0.0	13
Apr	2.6	3	1.9	7	3.0	7	1.8	10	2.8	10	2.4	11	2.6	9	2.5	12	1.4	13
May	9.9	12	9.9	14	8.3	5	7.0	7	9.0	10	9.0	9	9.2	6	9.1	9	8.6	11
Jun	17.7	9	16.3	14	12.9	5	11.9	9	14.2	11	14.1	11	14.1	9	13.7	10	14.2	13
Jul	21.3	12	20.2	14	17.0	4	15.8	12	18.0	12	17.5	14	17.9	11	16.7	15	17.6	15
Aug	21.4	14	19.7	14	16.2	6	16.2	12	18.2	12	17.7	14	17.6	11	16.1	15	17.2	16
Sep	17.5	16	15.9	15	13.4	7	12.8	12	14.1	12	13.9	13	14.0	12	12.7	16	13.1	16
Oct	10.9	16	8.4	17	7.4	8	6.8	12	8.0	11	7.7	13	8.0	12	7.1	14	7.2	15
Nov	4.0	6	2.9	9	2.8	8	2.0	12	2.7	10	2.4	11	2.4	12	3.1	15	2.4	14
Dec	0.5	5	0.3	9	1.1	8	0.2	12	0.4	13	0.4	14	0.3	12	0.6	15	0.3	16
Summer	21.3	12	20.0	14	16.6	4	16.0	12	18.1	12	17.6	14	17.8	11	16.4	15	17.4	15

Summer : mean value of July and August

n : number of years used in the calculation of the average. For summer, n = minimum between July and August

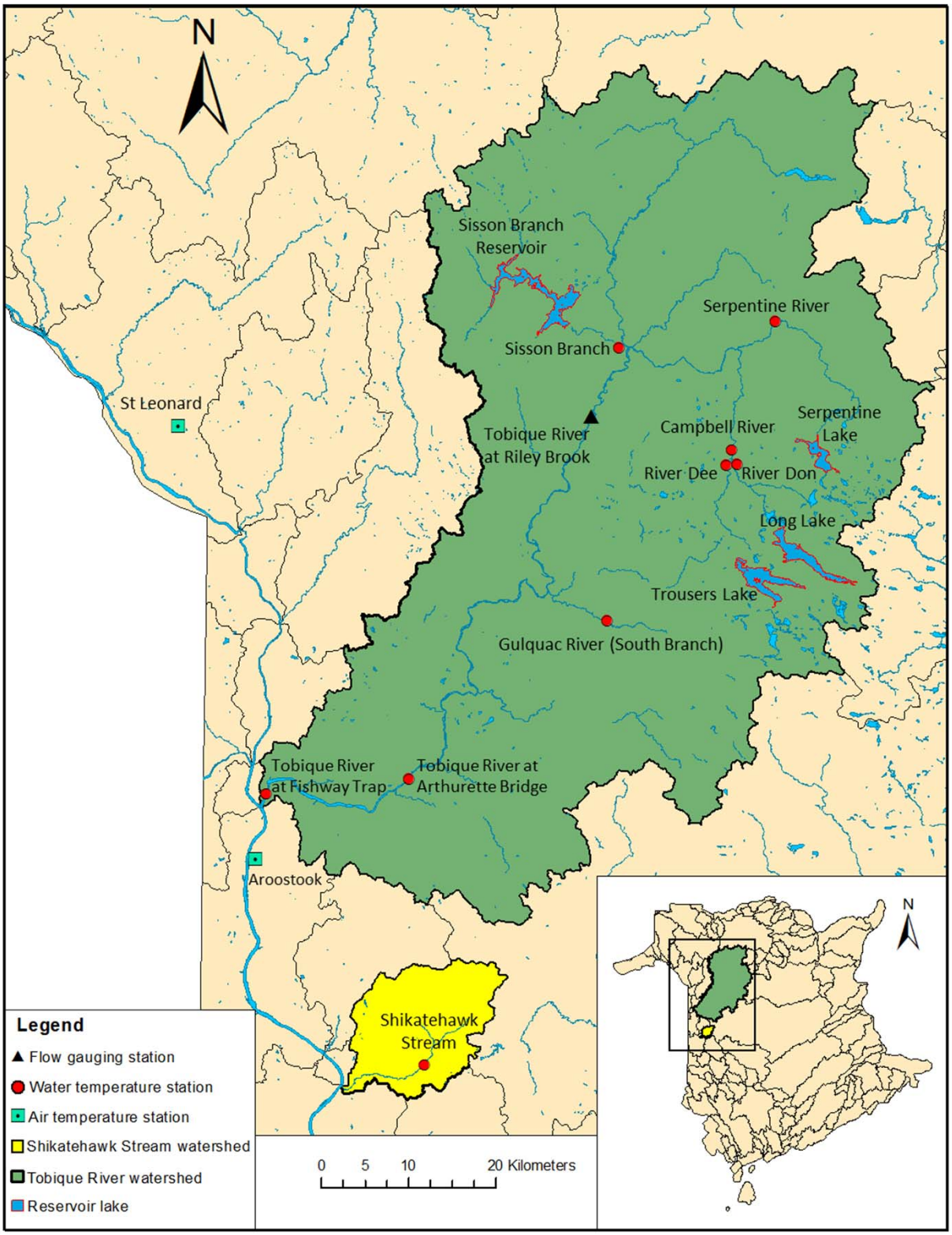

Figure 1. Location of the Tobique River, Shikatehawk Stream, meteorological stations and discharge gauging station

Figure 2. Photo of the Vemco minilog installed within a PVC protective casing for field deployment

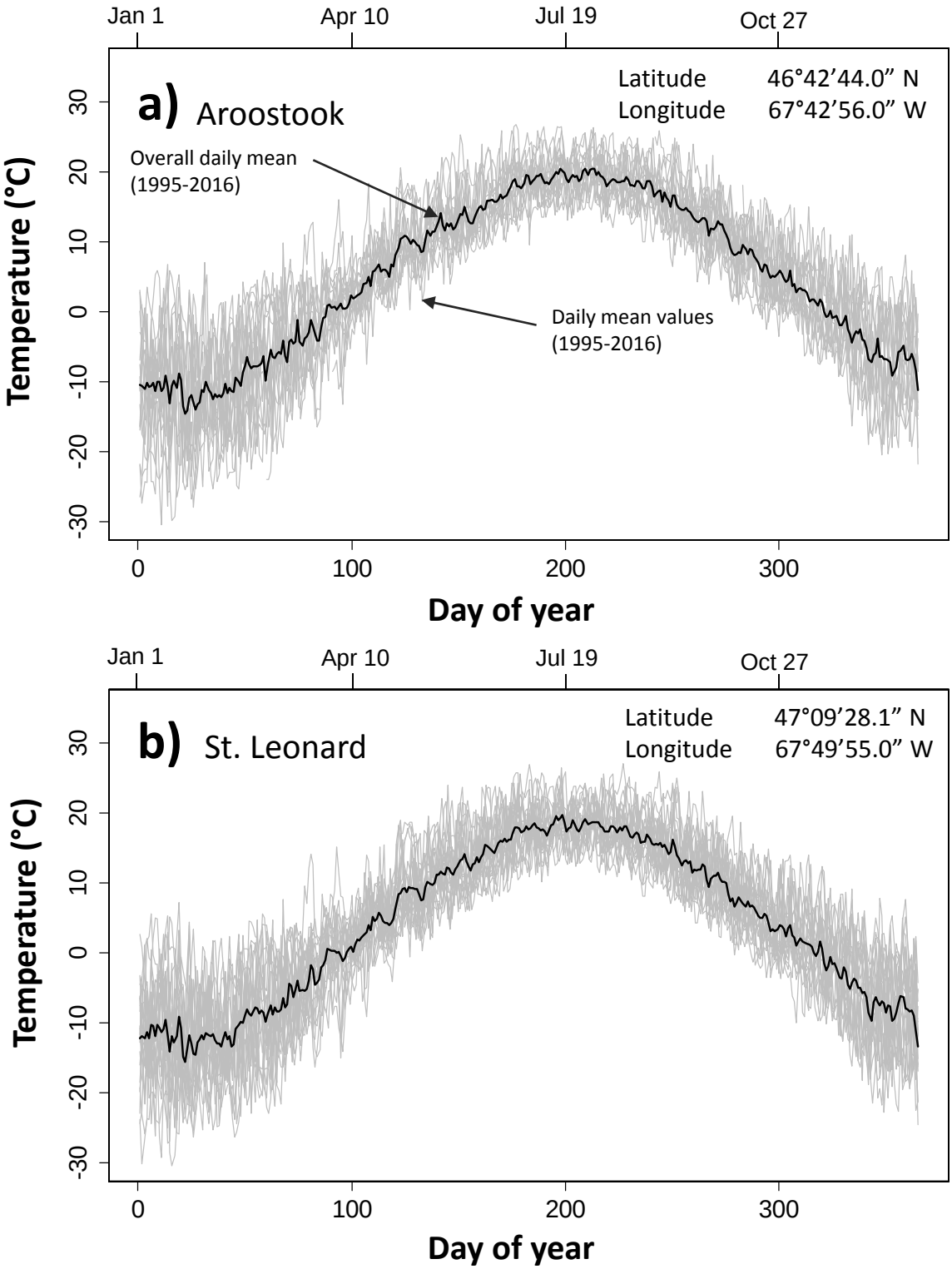

Figure 3. Air temperature regime and mean temperatures at a) Aroostook and b) St. Leonard

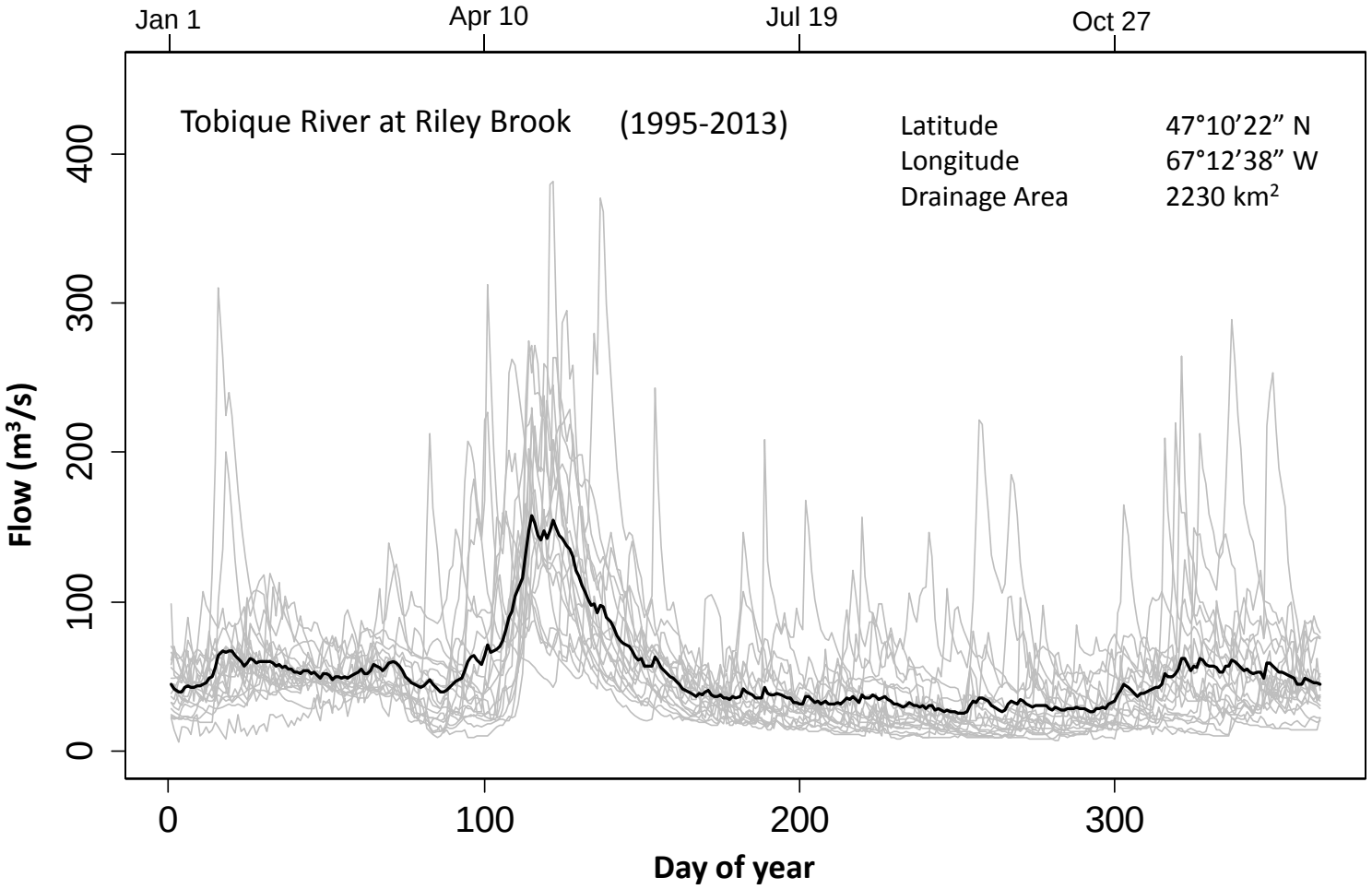

Figure 4. Flow regime and overall mean from 1995 to 2013 at the Riley Brook gauging station on Tobique River

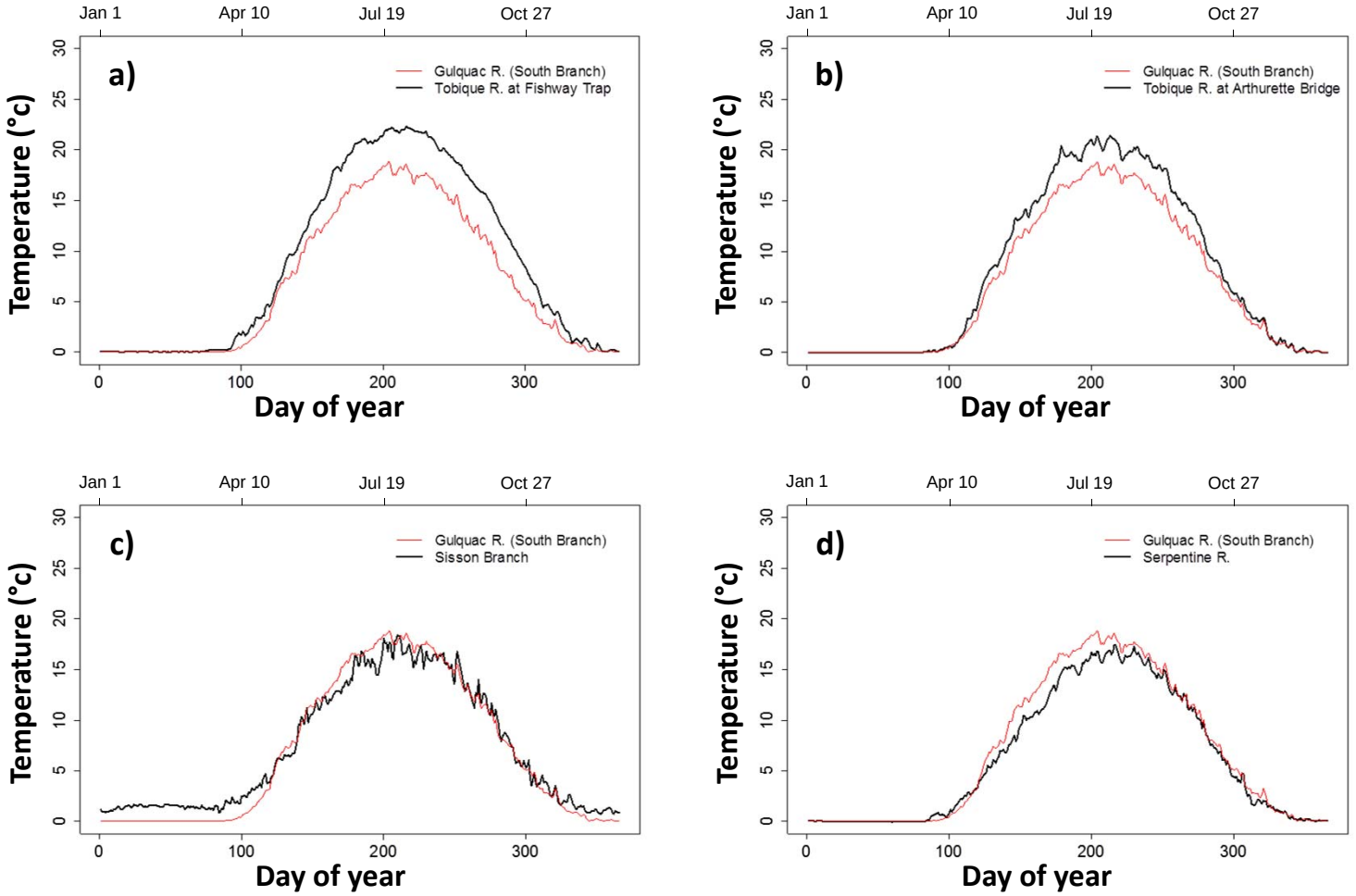

Figure 5. Comparison of overall mean values between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

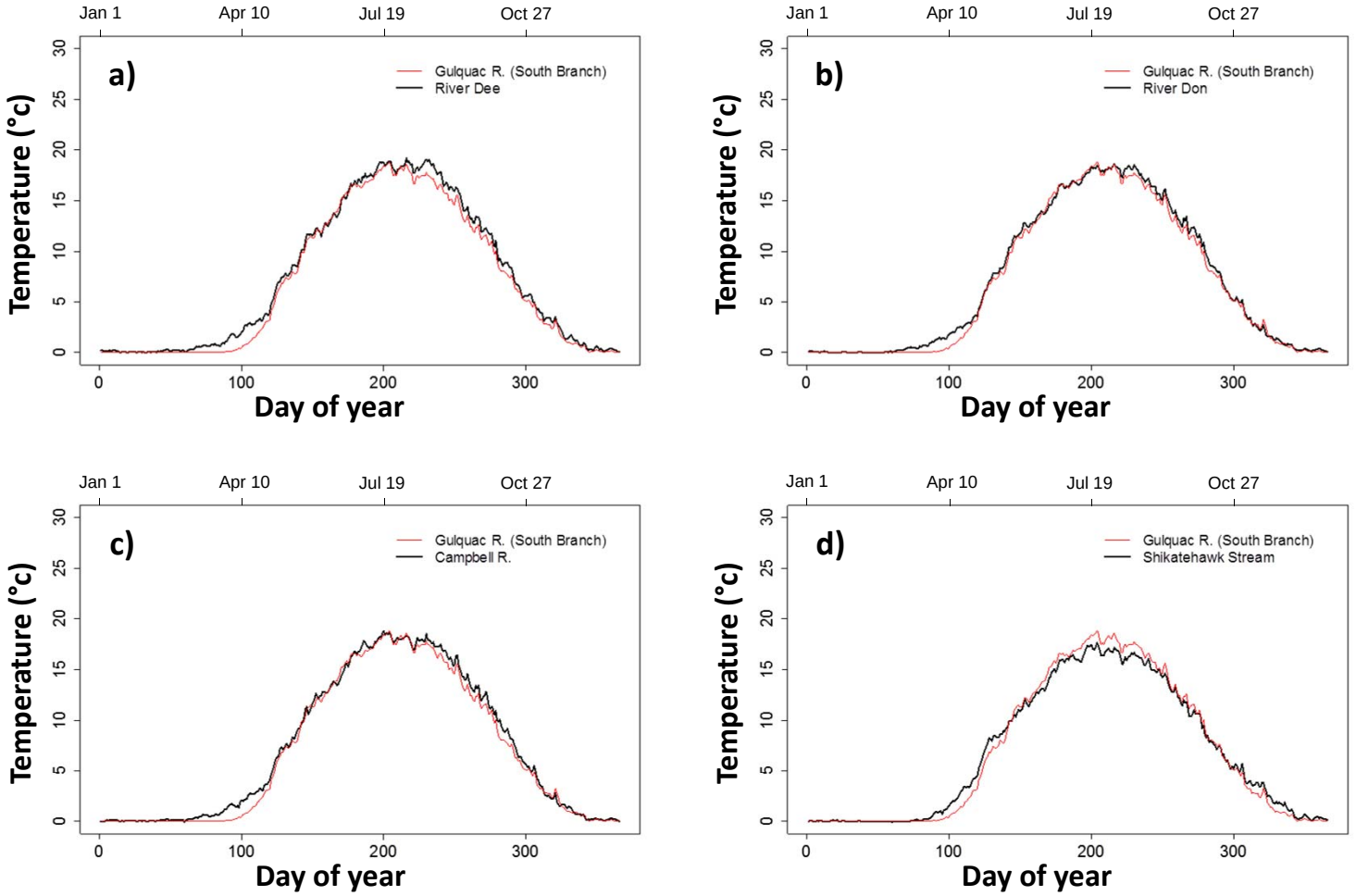

Figure 6. Comparison of overall mean values between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

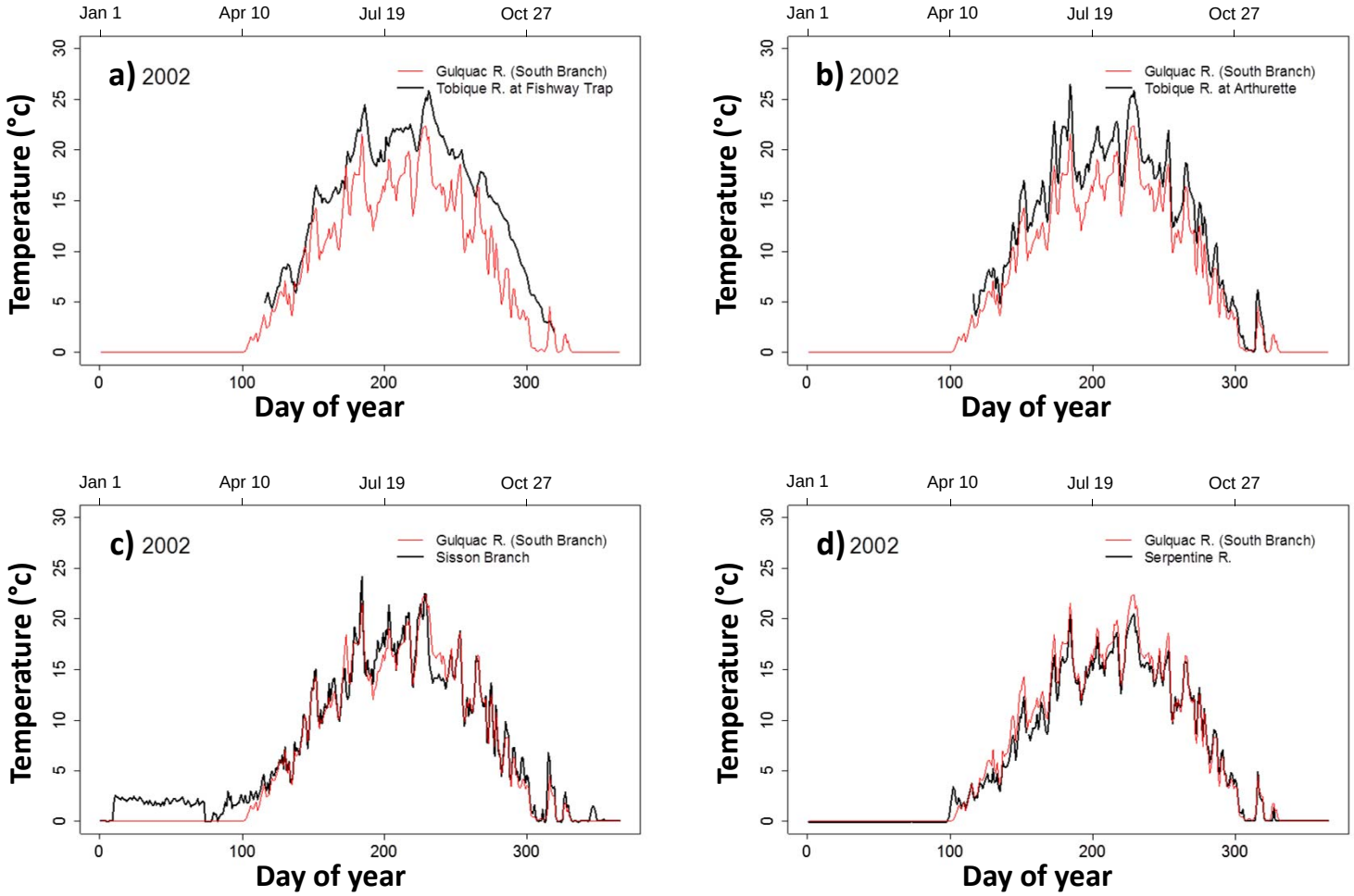

Figure 7. Comparison of daily mean values for 2002 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

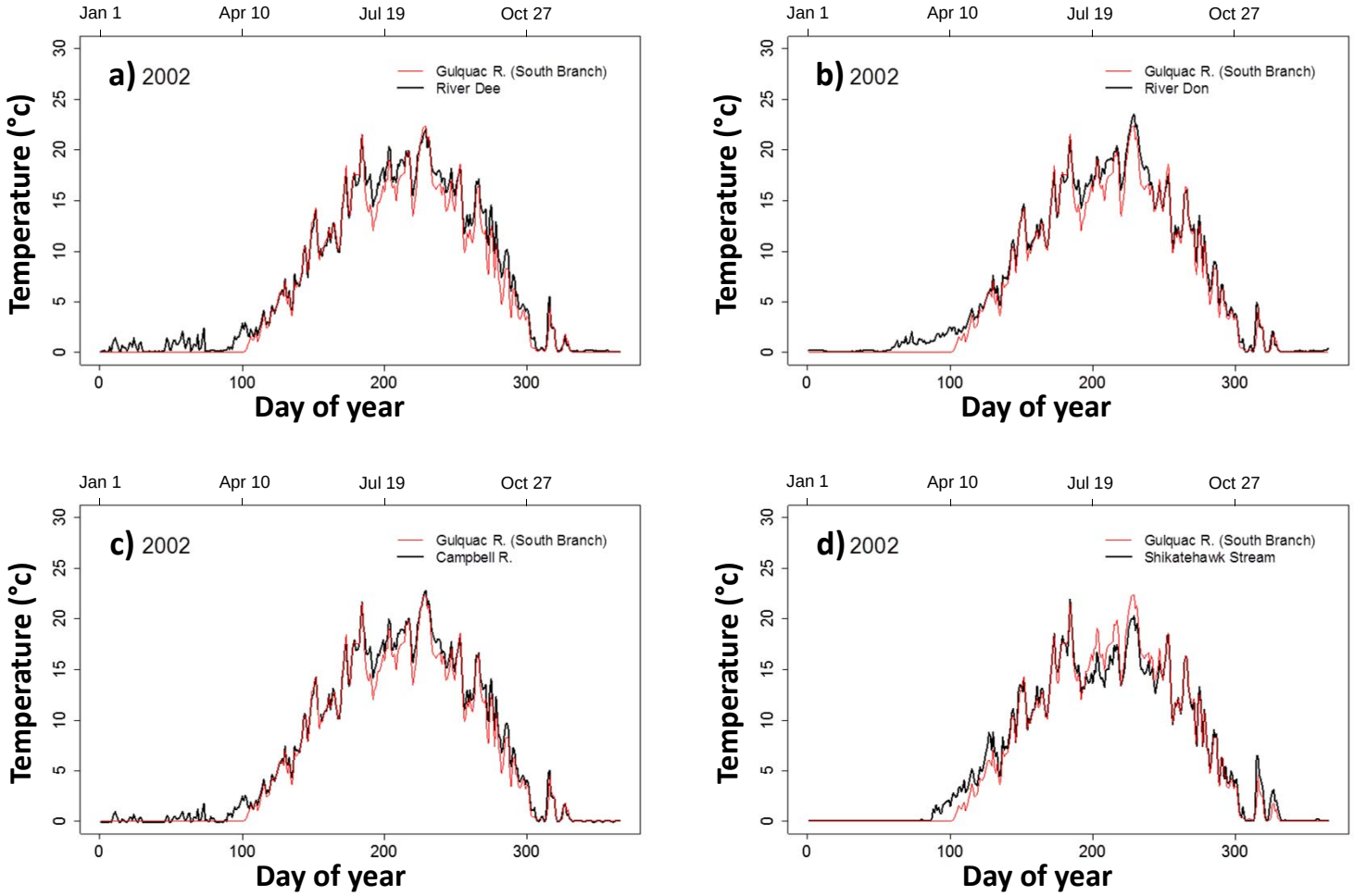

Figure 8. Comparison of daily mean values for 2002 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

Appendix A

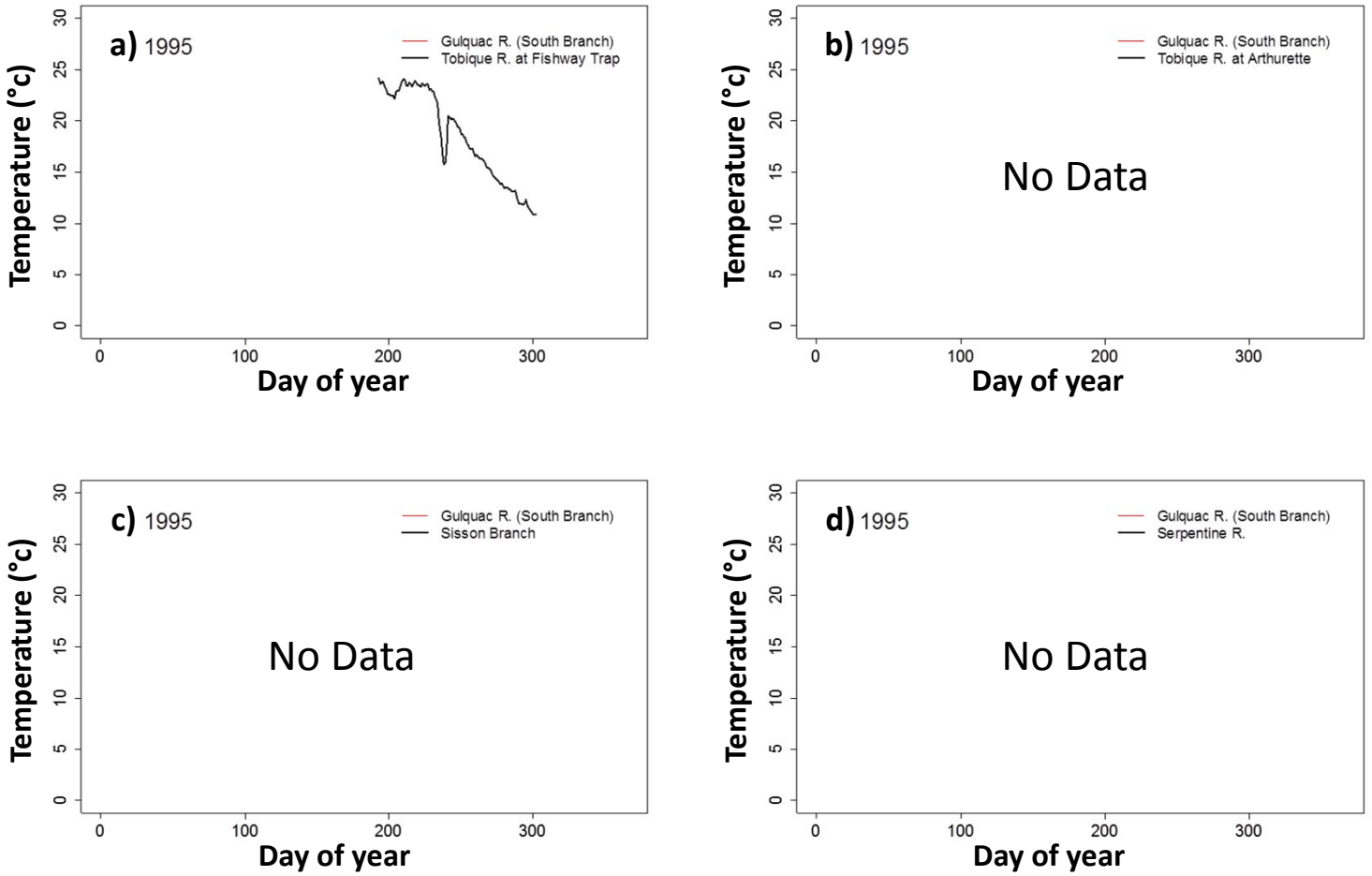

Figure A1. Comparison of daily mean values for 1995 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

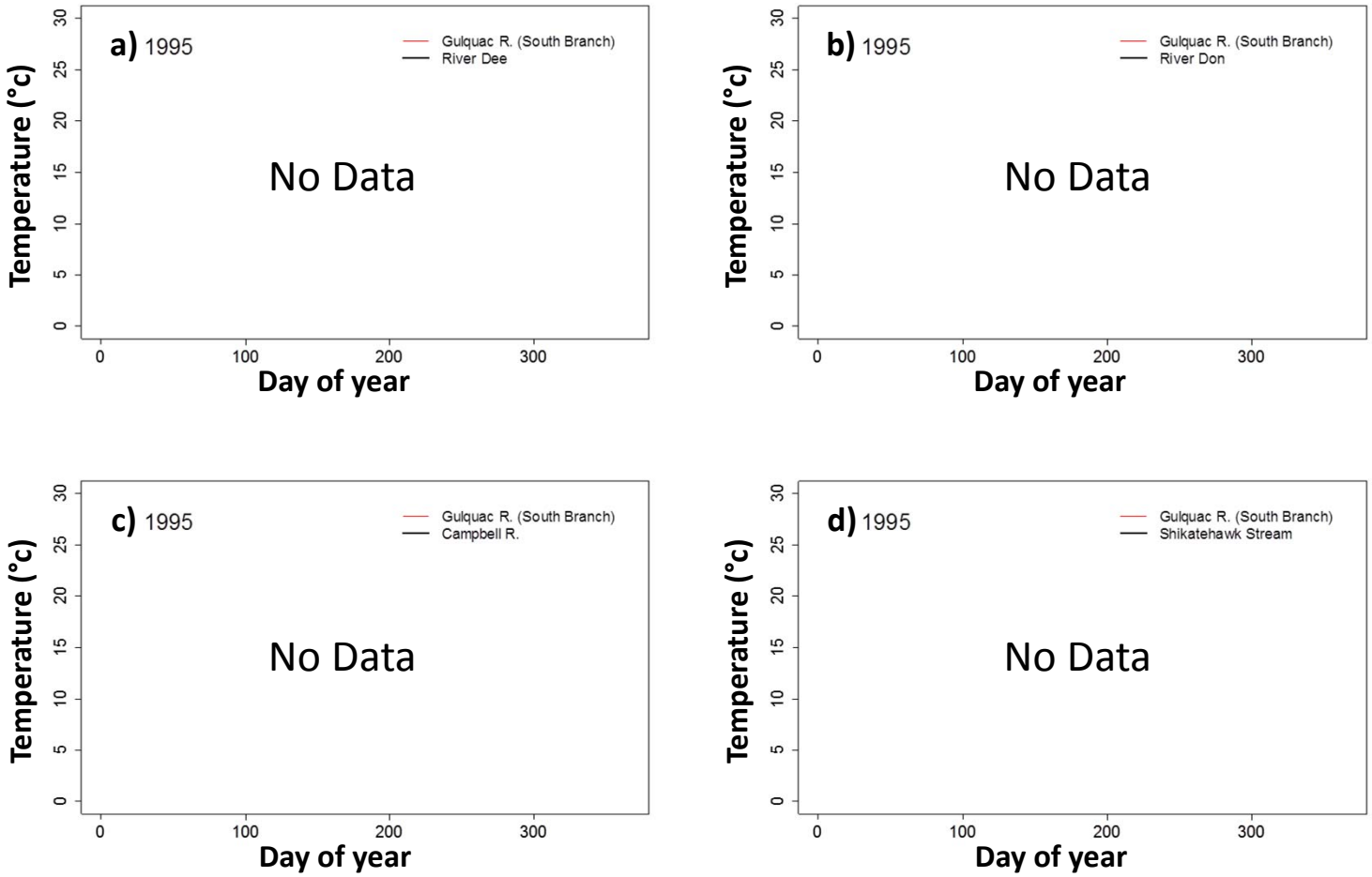

Figure A2. Comparison of daily mean values for 1995 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

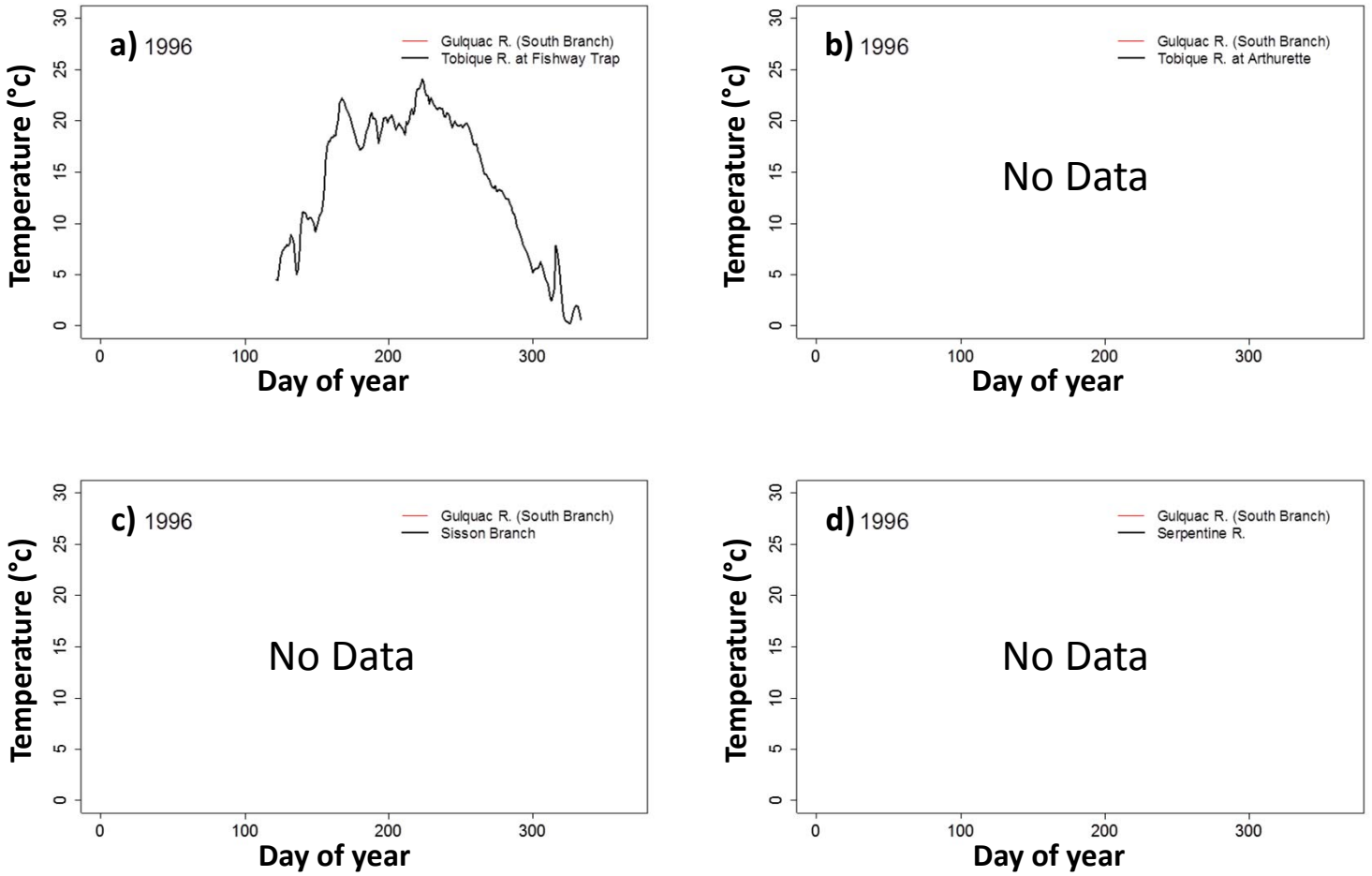

Figure A3. Comparison of daily mean values for 1996 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

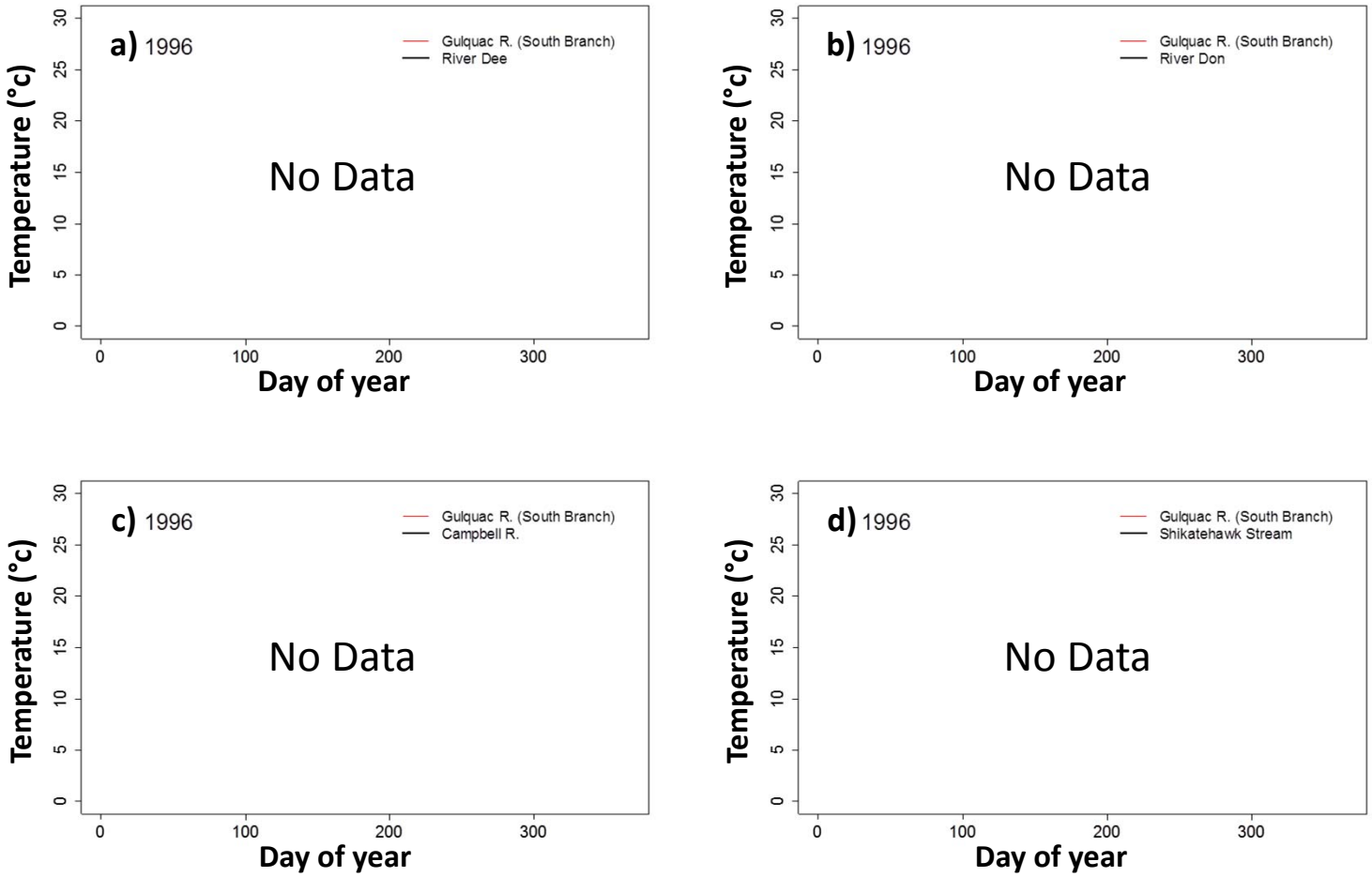

Figure A4. Comparison of daily mean values for 1996 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

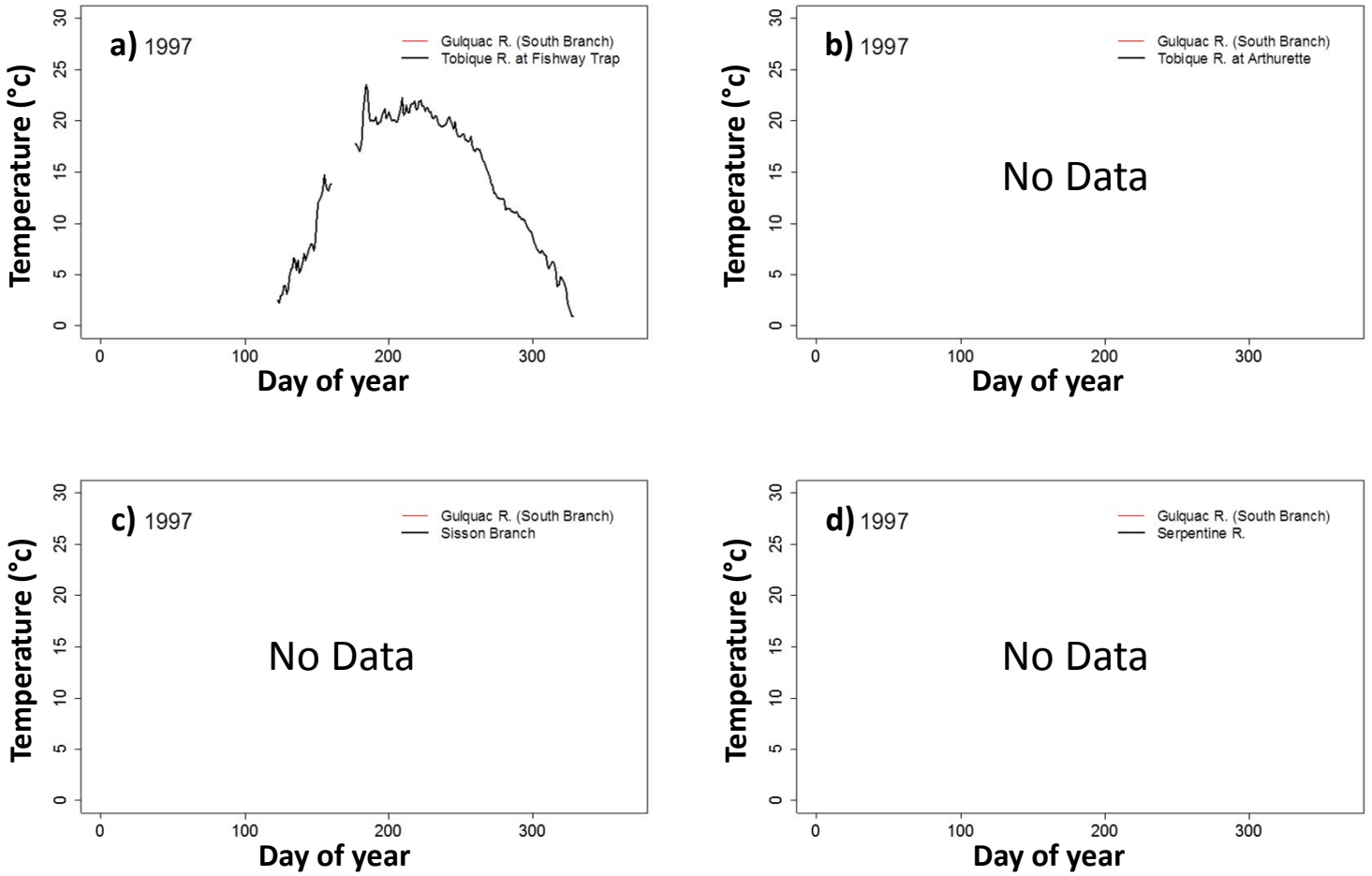

Figure A5. Comparison of daily mean values for 1997 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

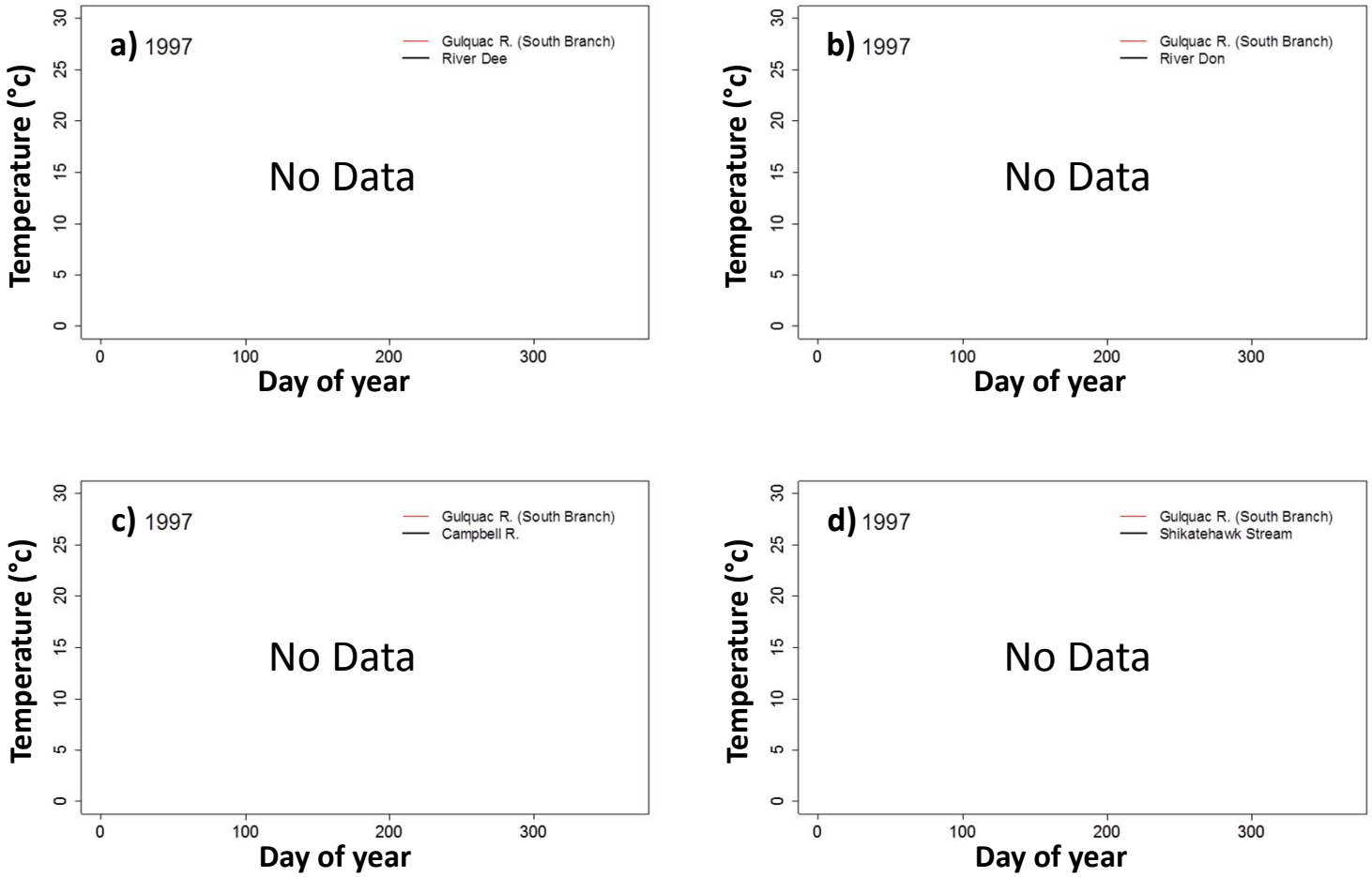

Figure A6. Comparison of daily mean values for 1997 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

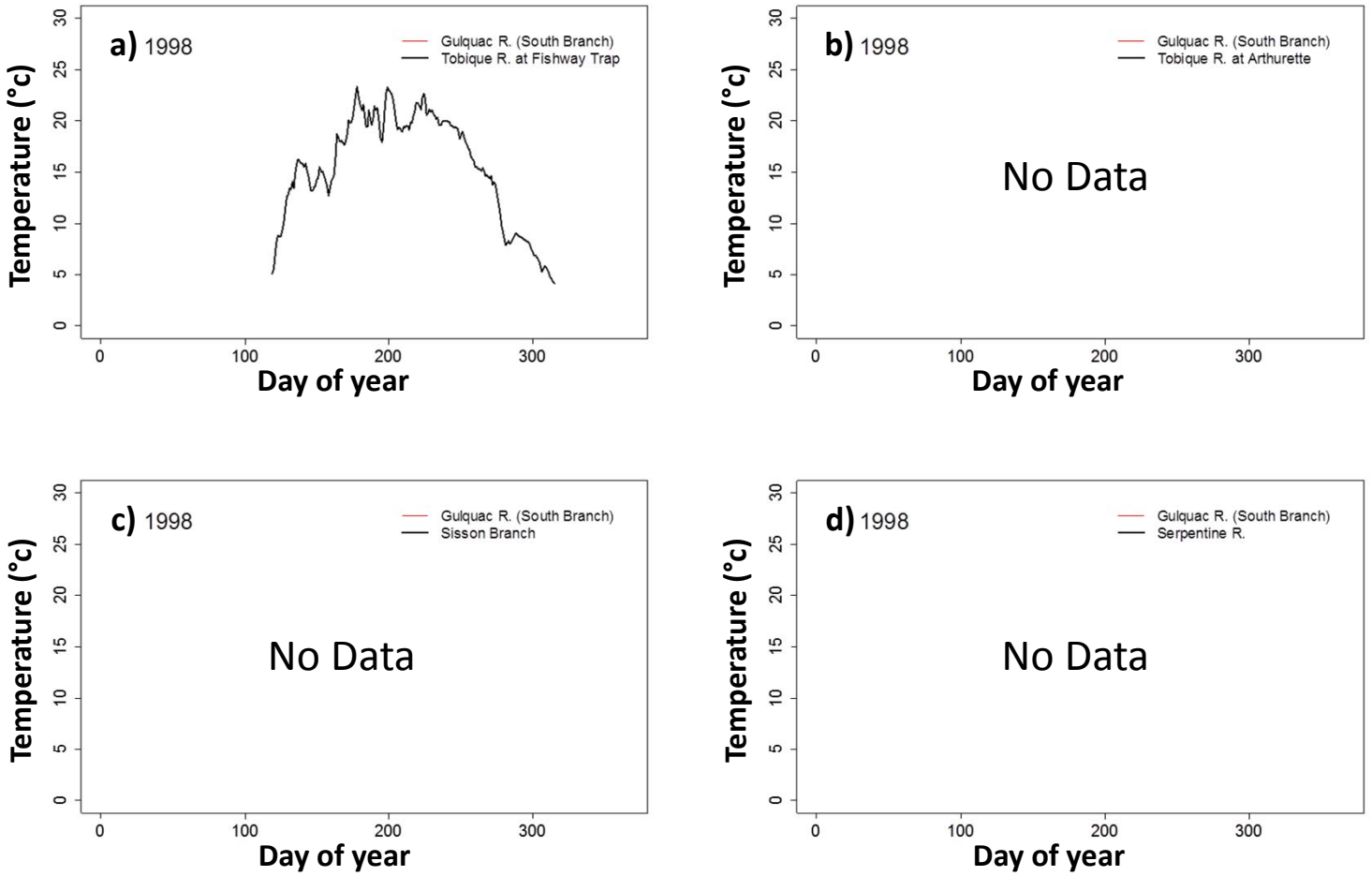

Figure A7. Comparison of daily mean values for 1998 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

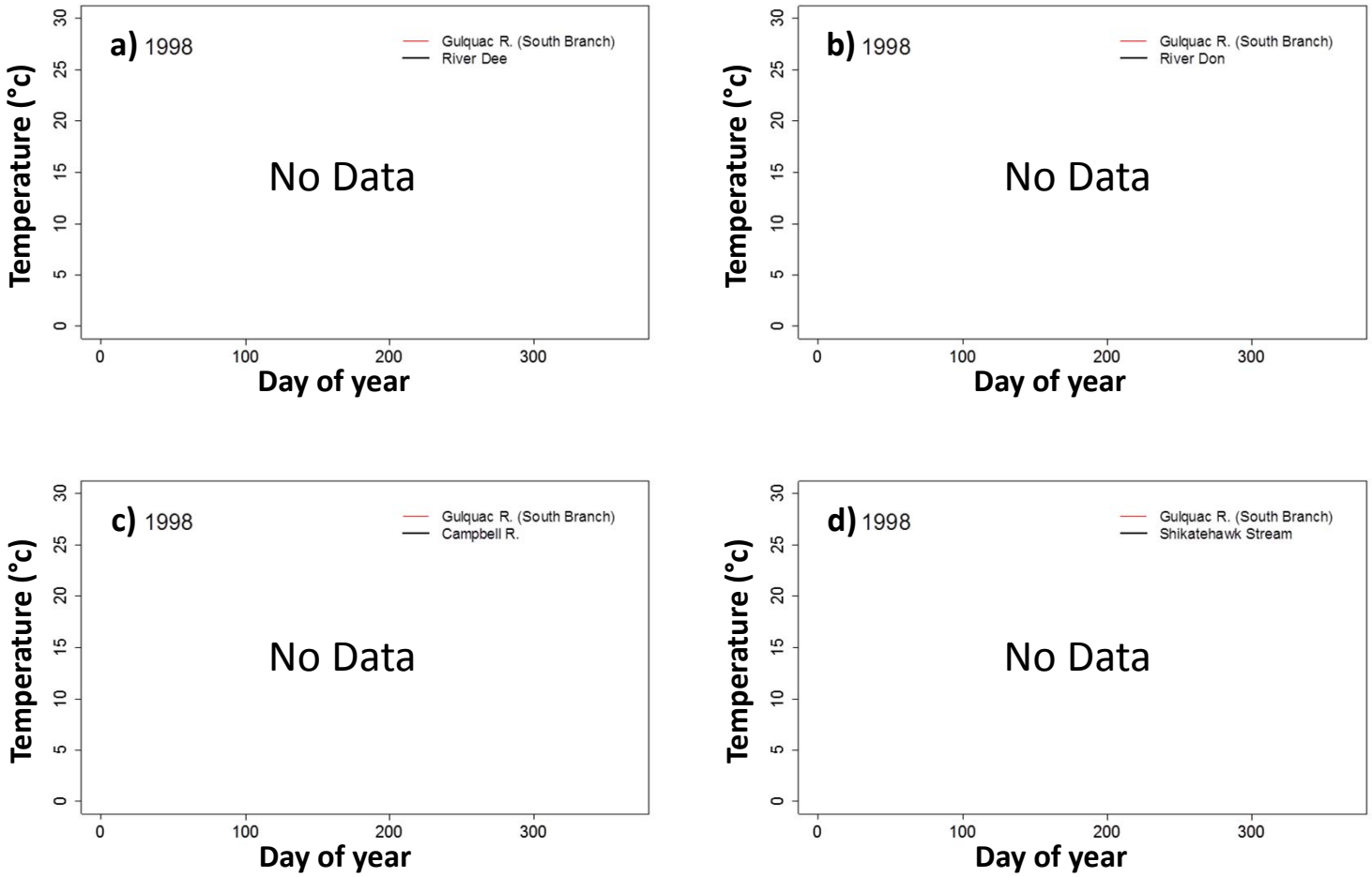

Figure A8. Comparison of daily mean values for 1998 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

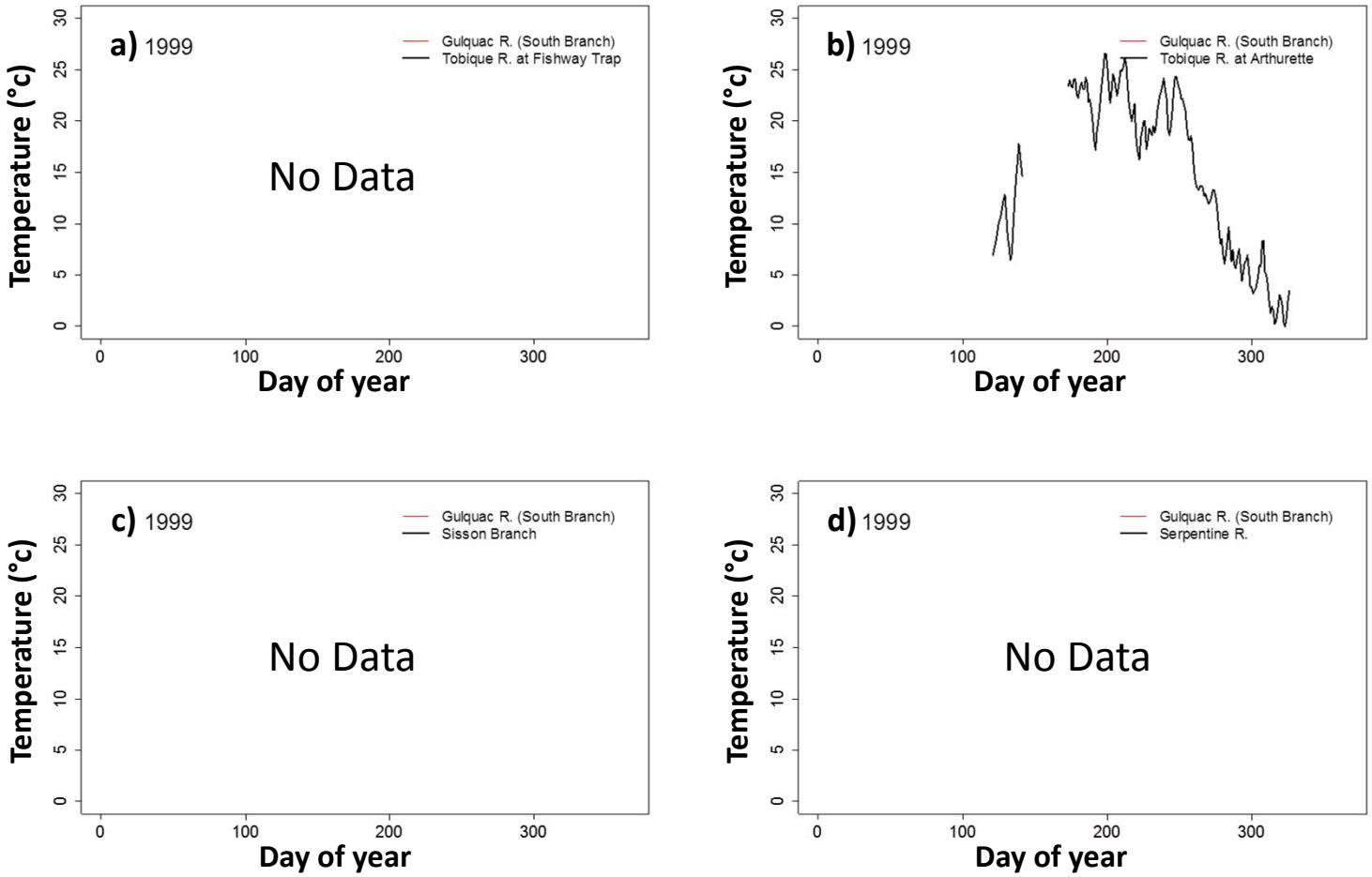

Figure A9. Comparison of daily mean values for 1999 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

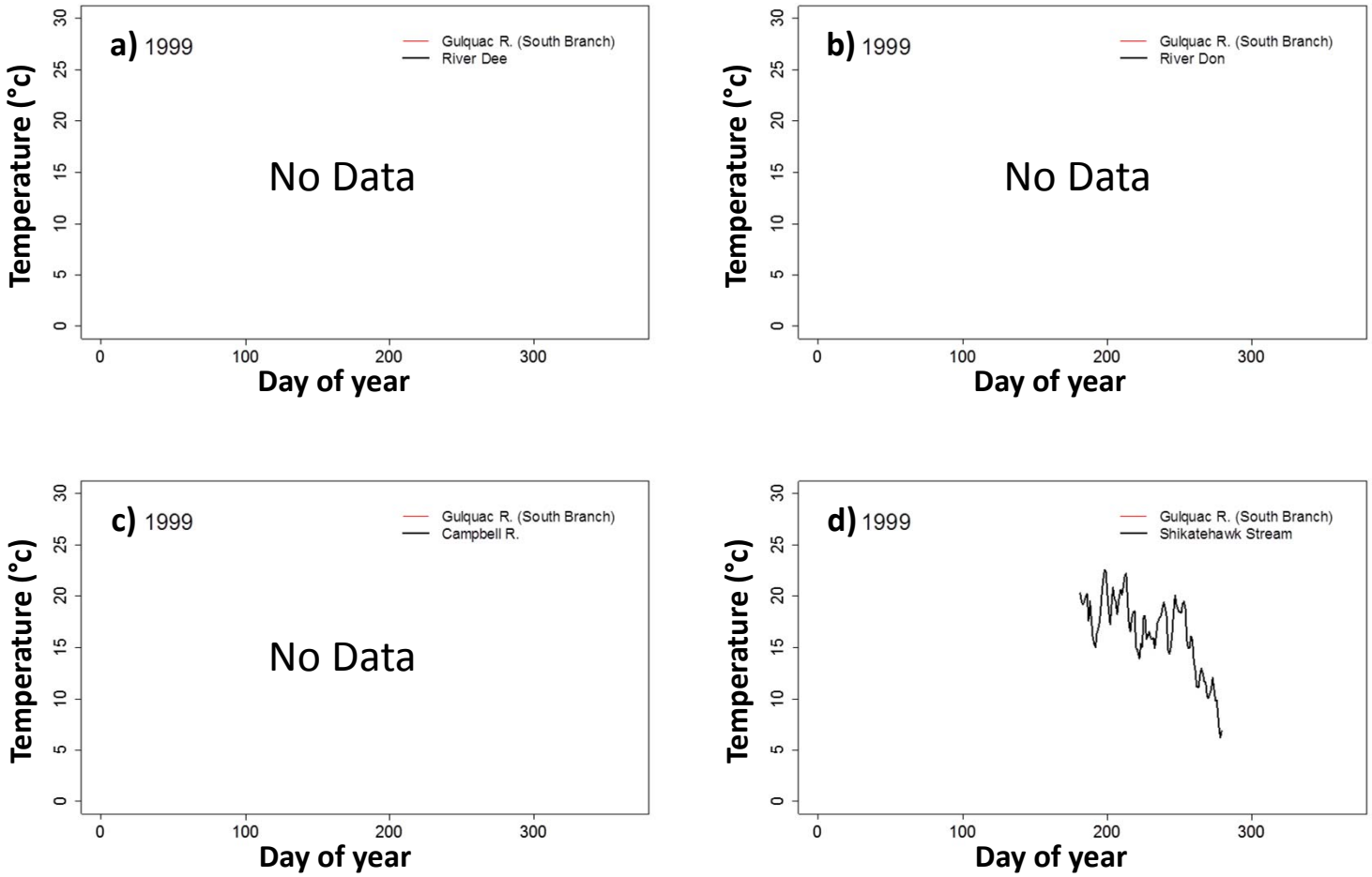

Figure A10. Comparison of daily mean values for 1999 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

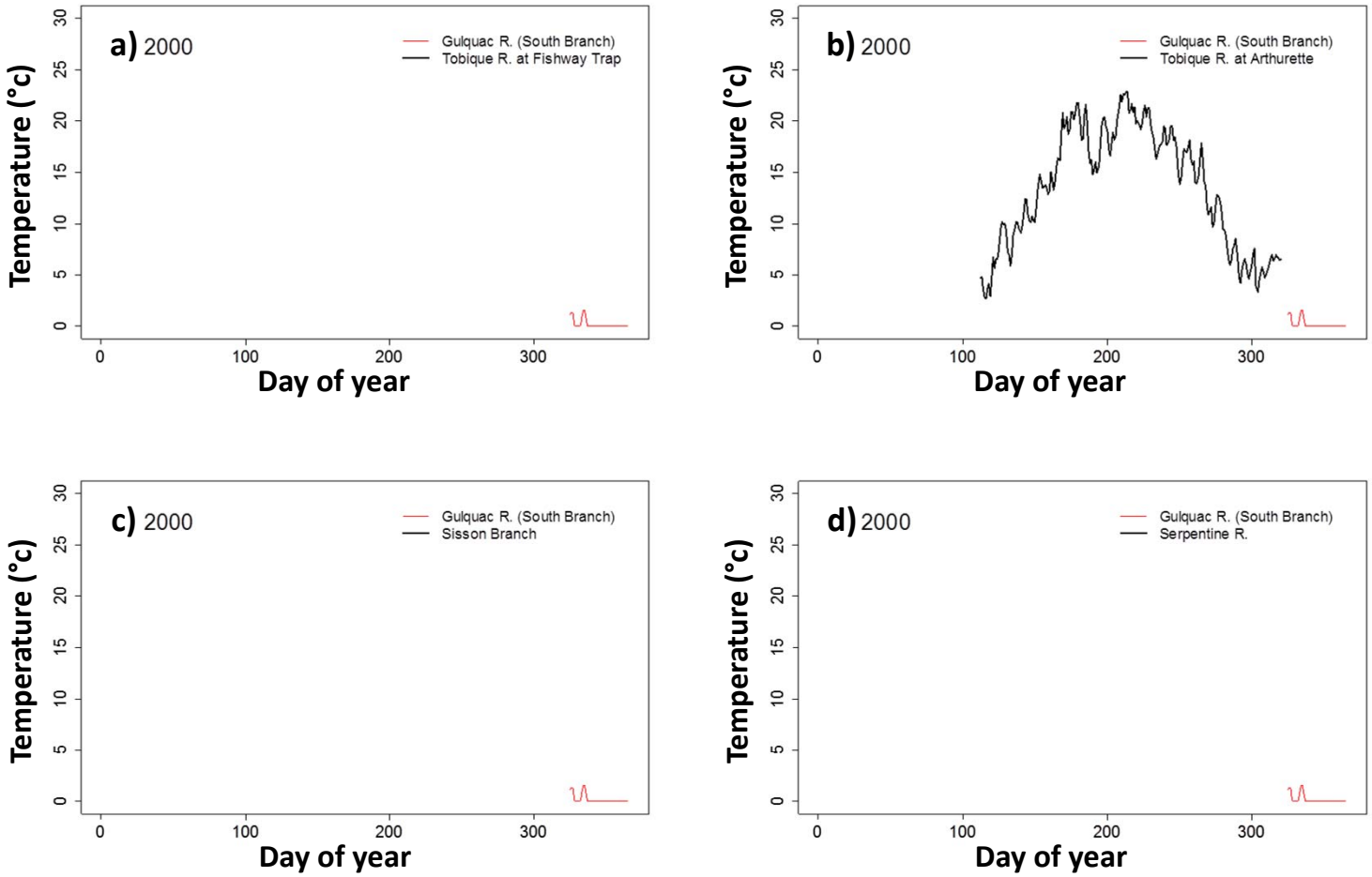

Figure A11. Comparison of daily mean values for 2000 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

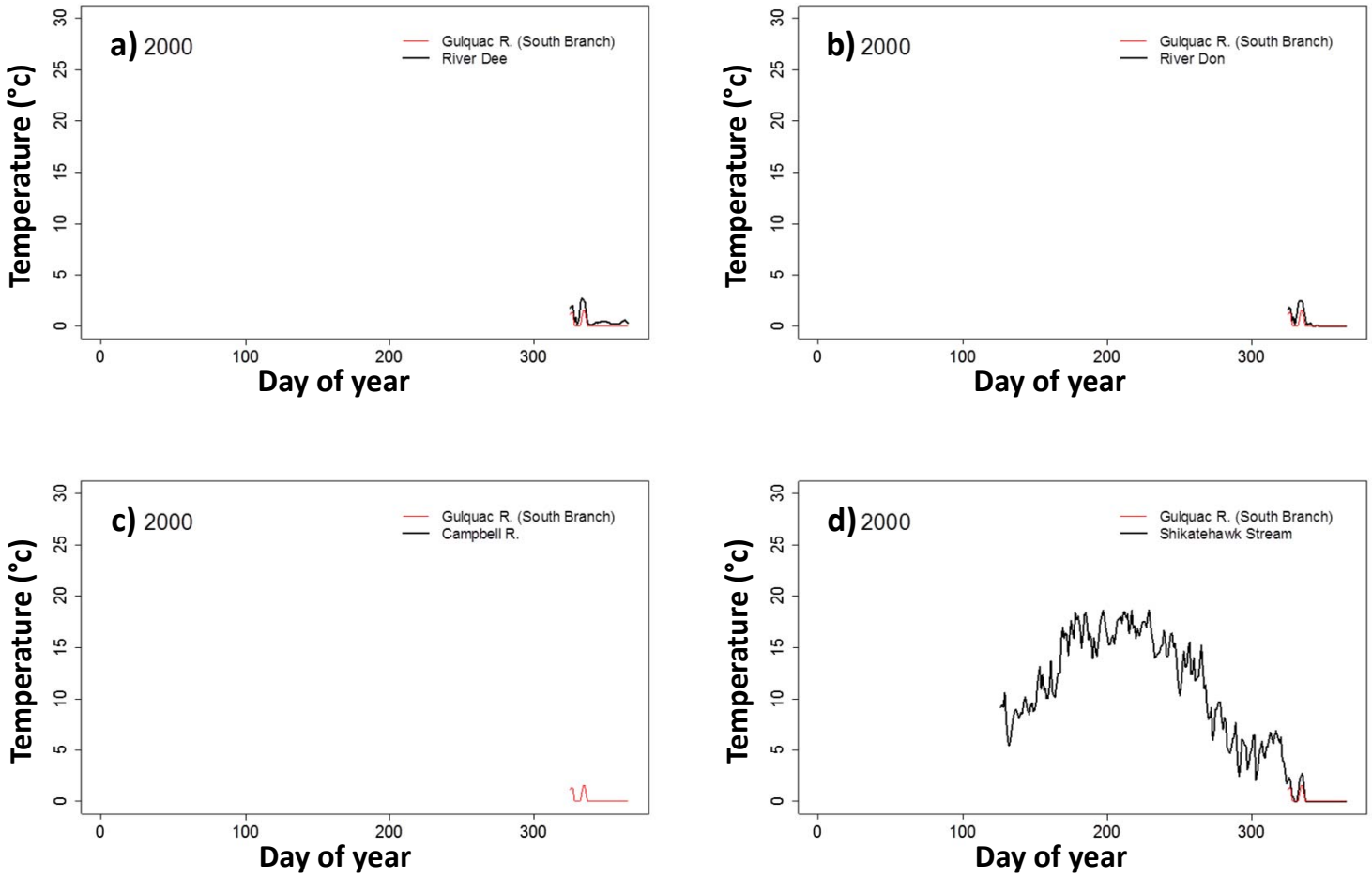

Figure A12. Comparison of daily mean values for 2000 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

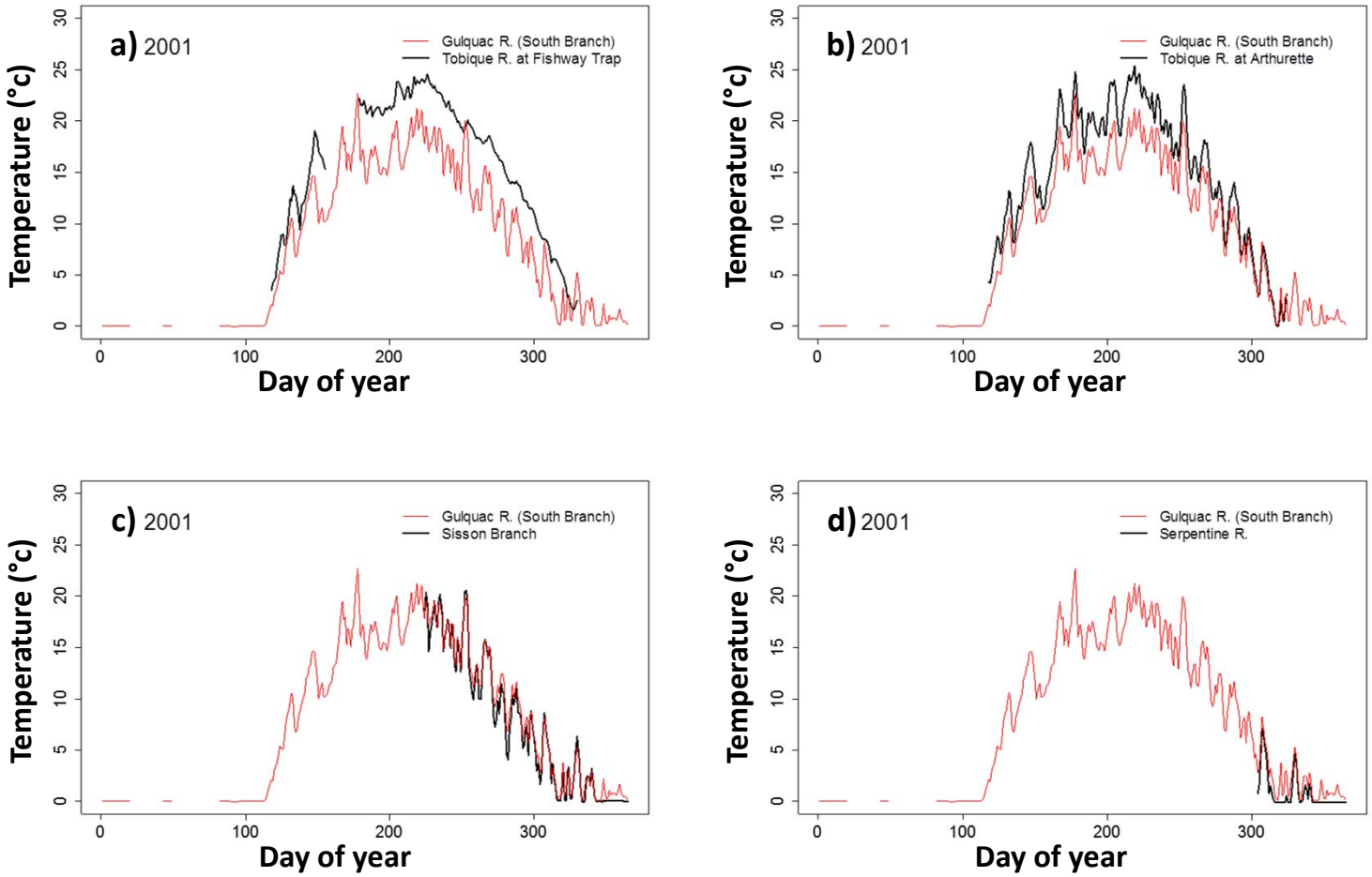

Figure A13. Comparison of daily mean values for 2001 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

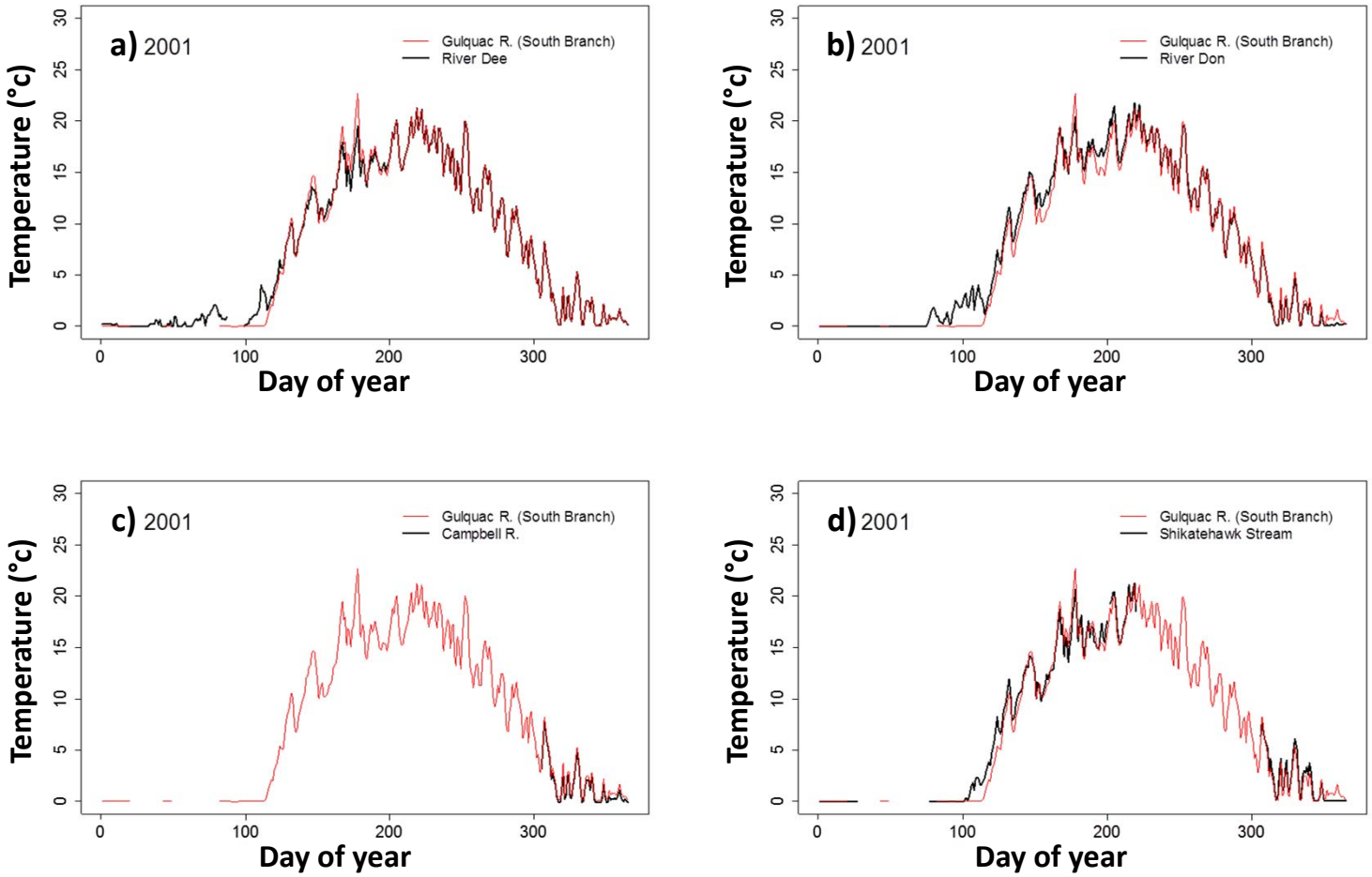

Figure A14. Comparison of daily mean values for 2001 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

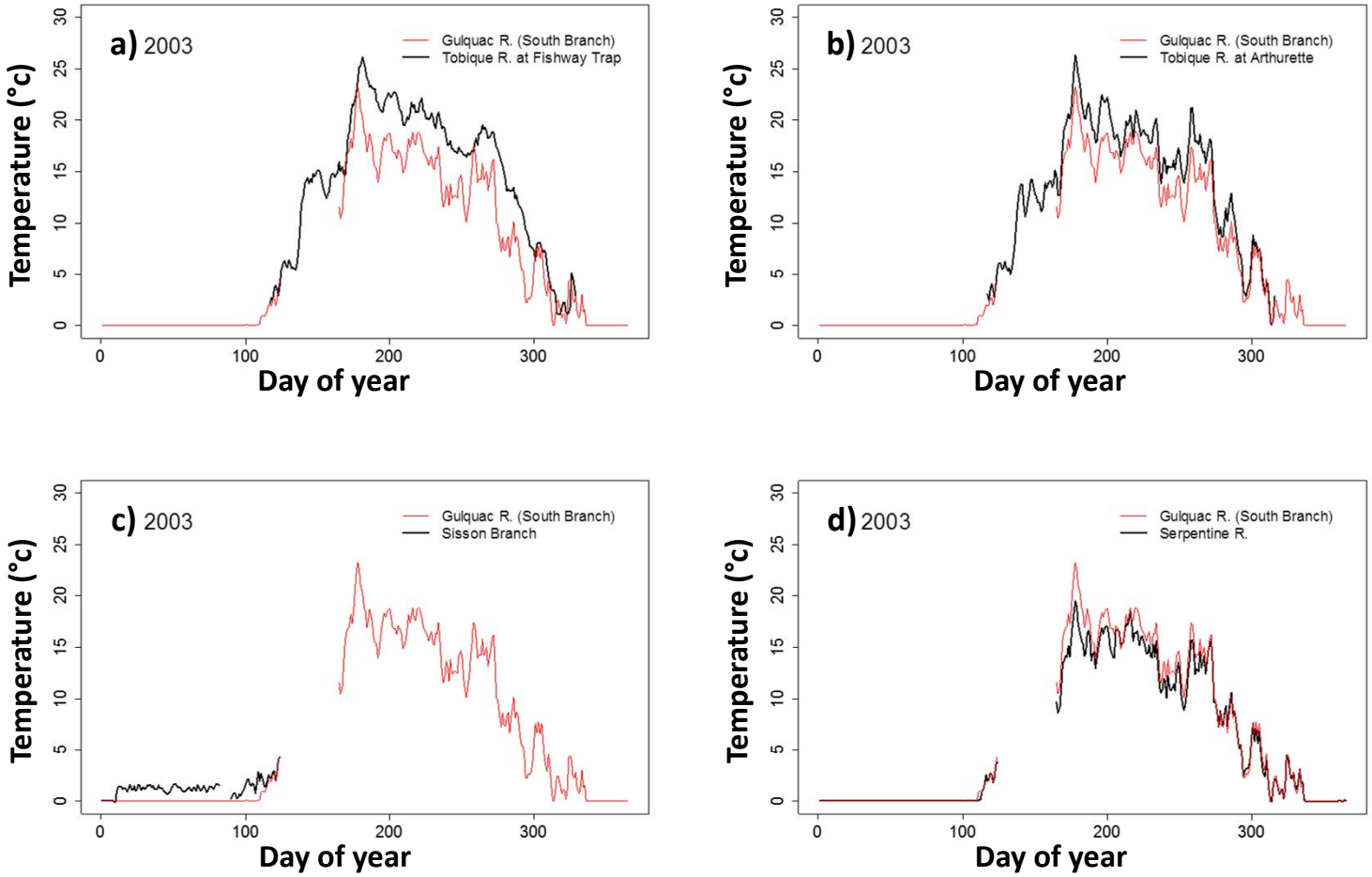

Figure A15. Comparison of daily mean values for 2003 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

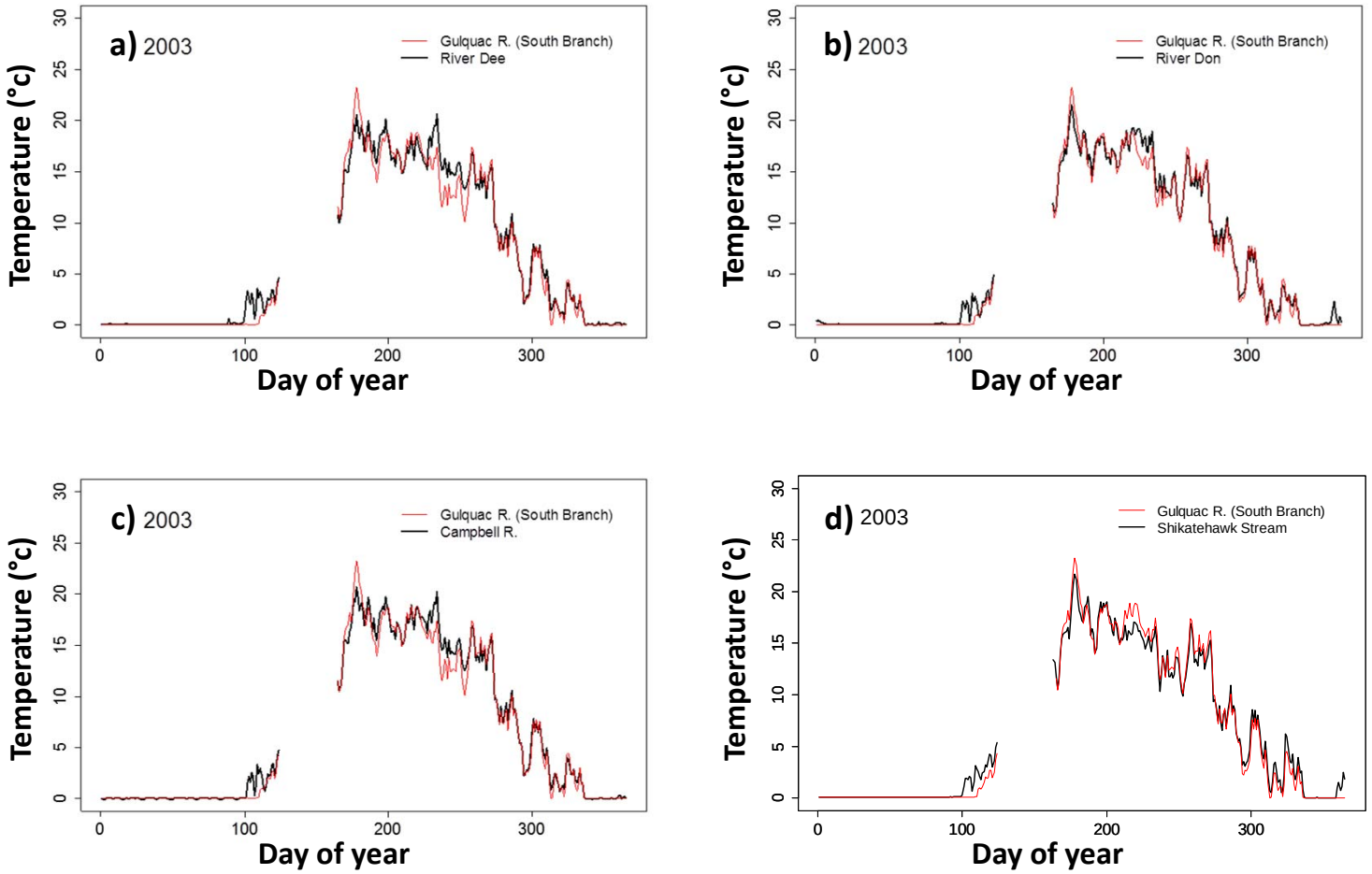

Figure A16. Comparison of daily mean values for 2003 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

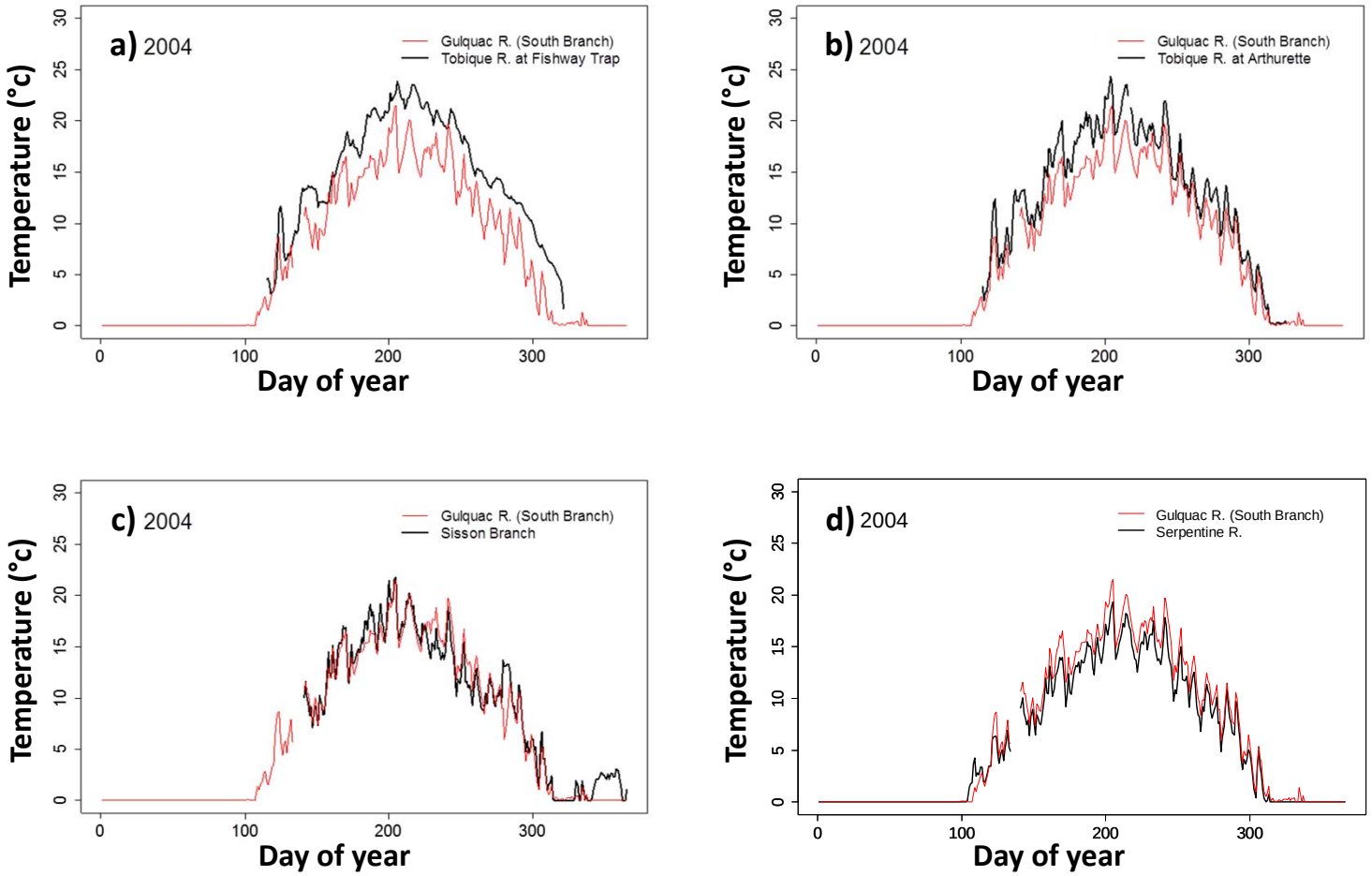

Figure A17. Comparison of daily mean values for 2004 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

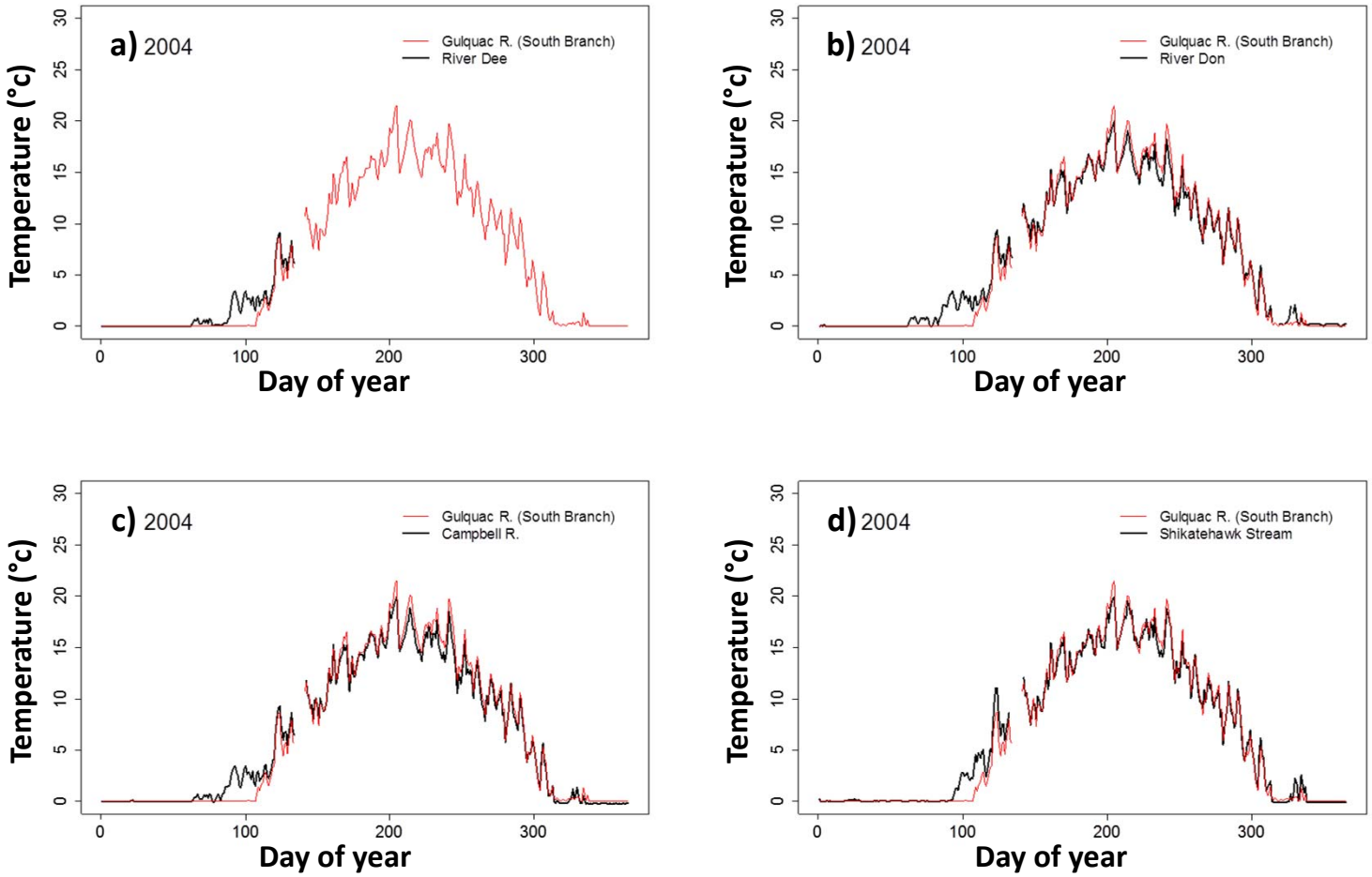

Figure A18. Comparison of daily mean values for 2004 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

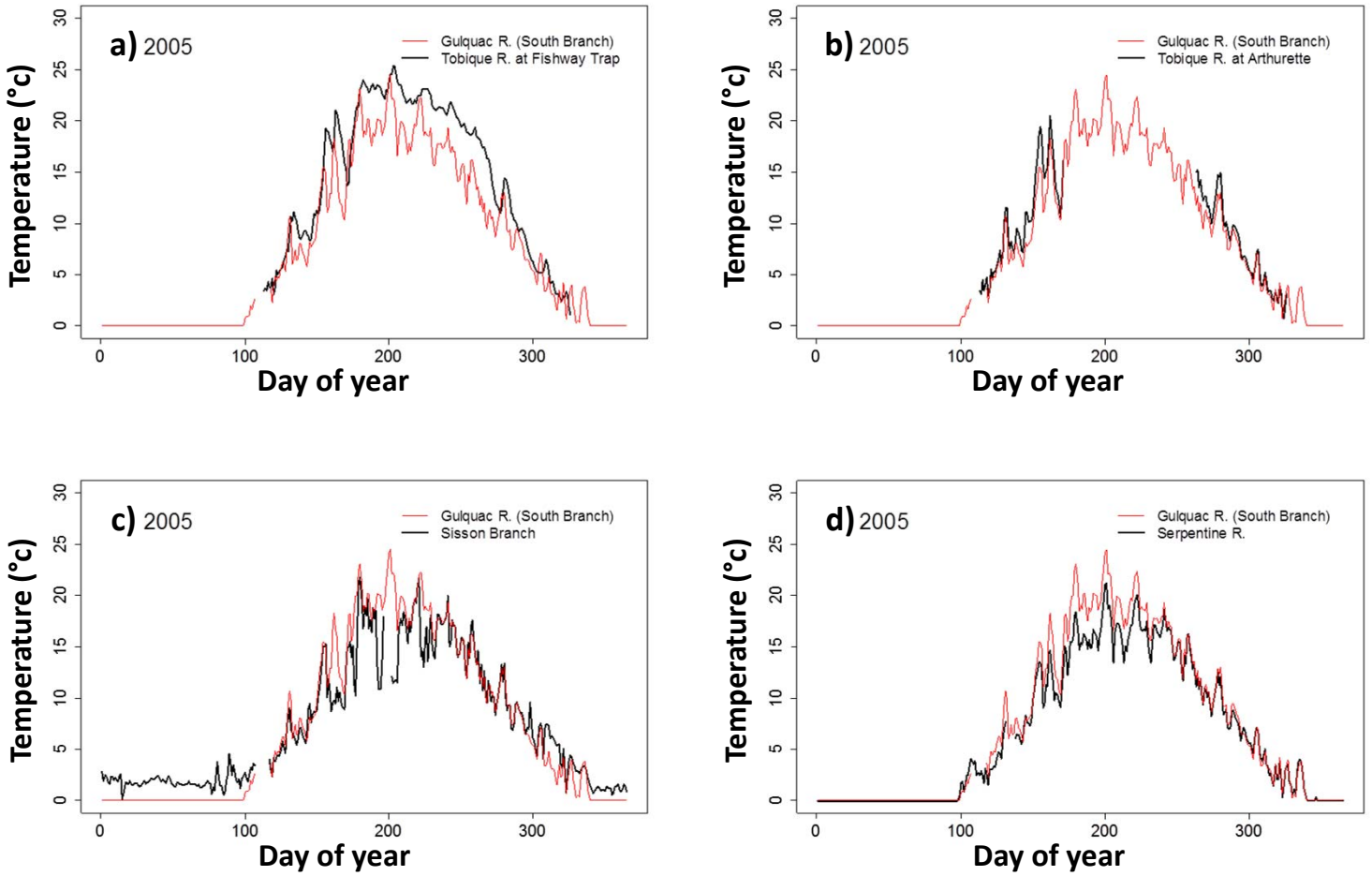

Figure A19. Comparison of daily mean values for 2005 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

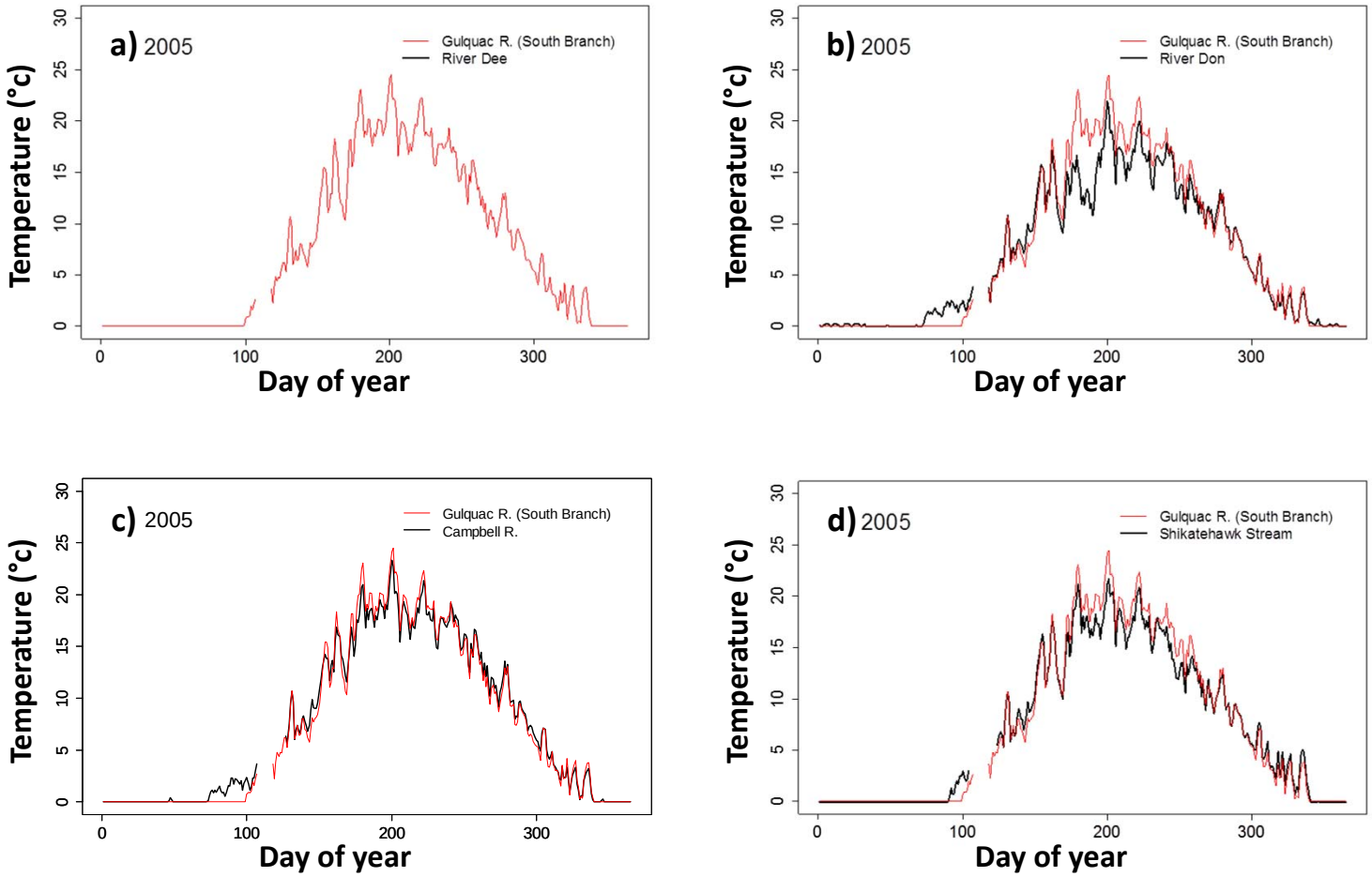

Figure A20. Comparison of daily mean values for 2005 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

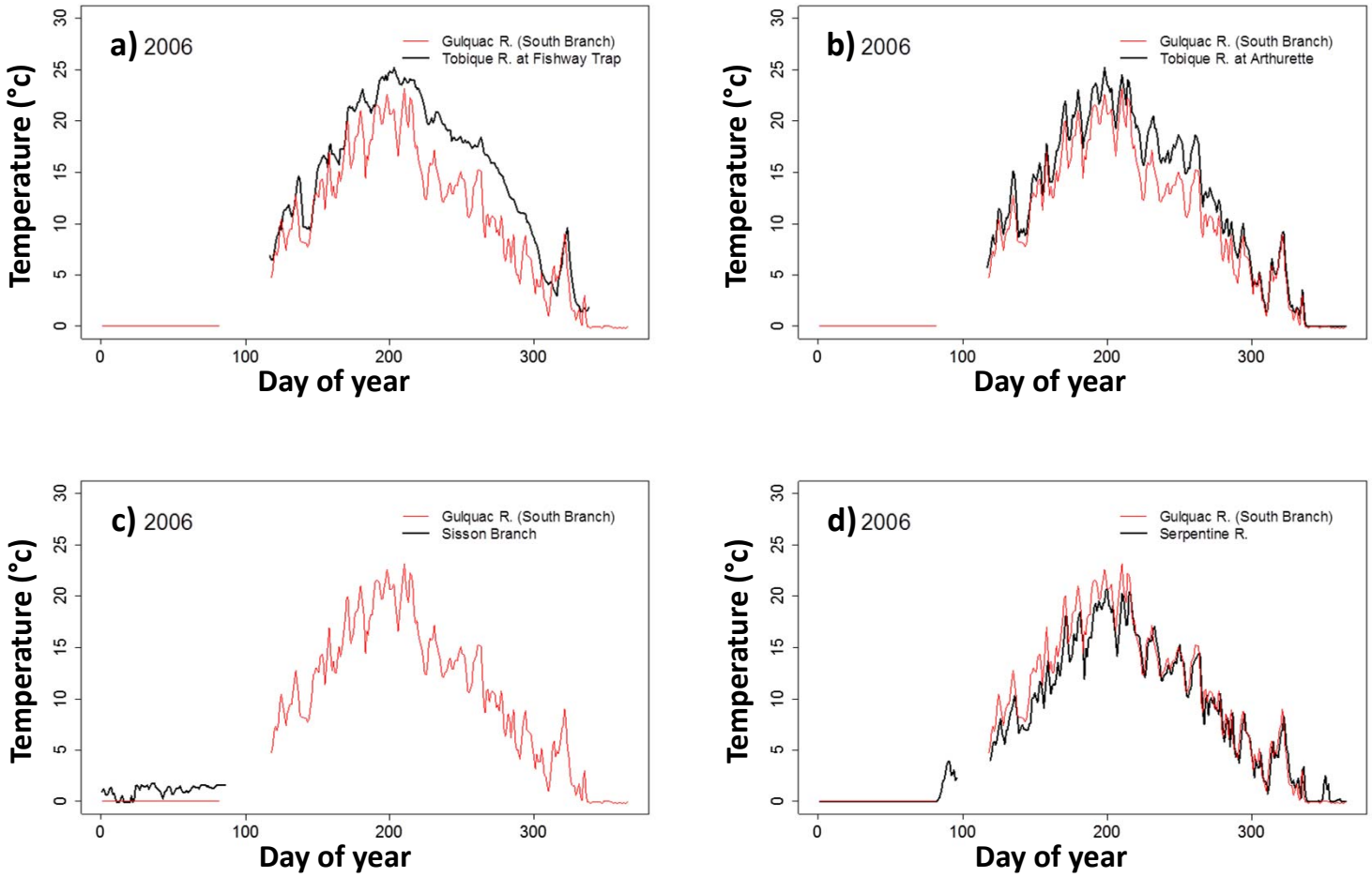

Figure A21. Comparison of daily mean values for 2006 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

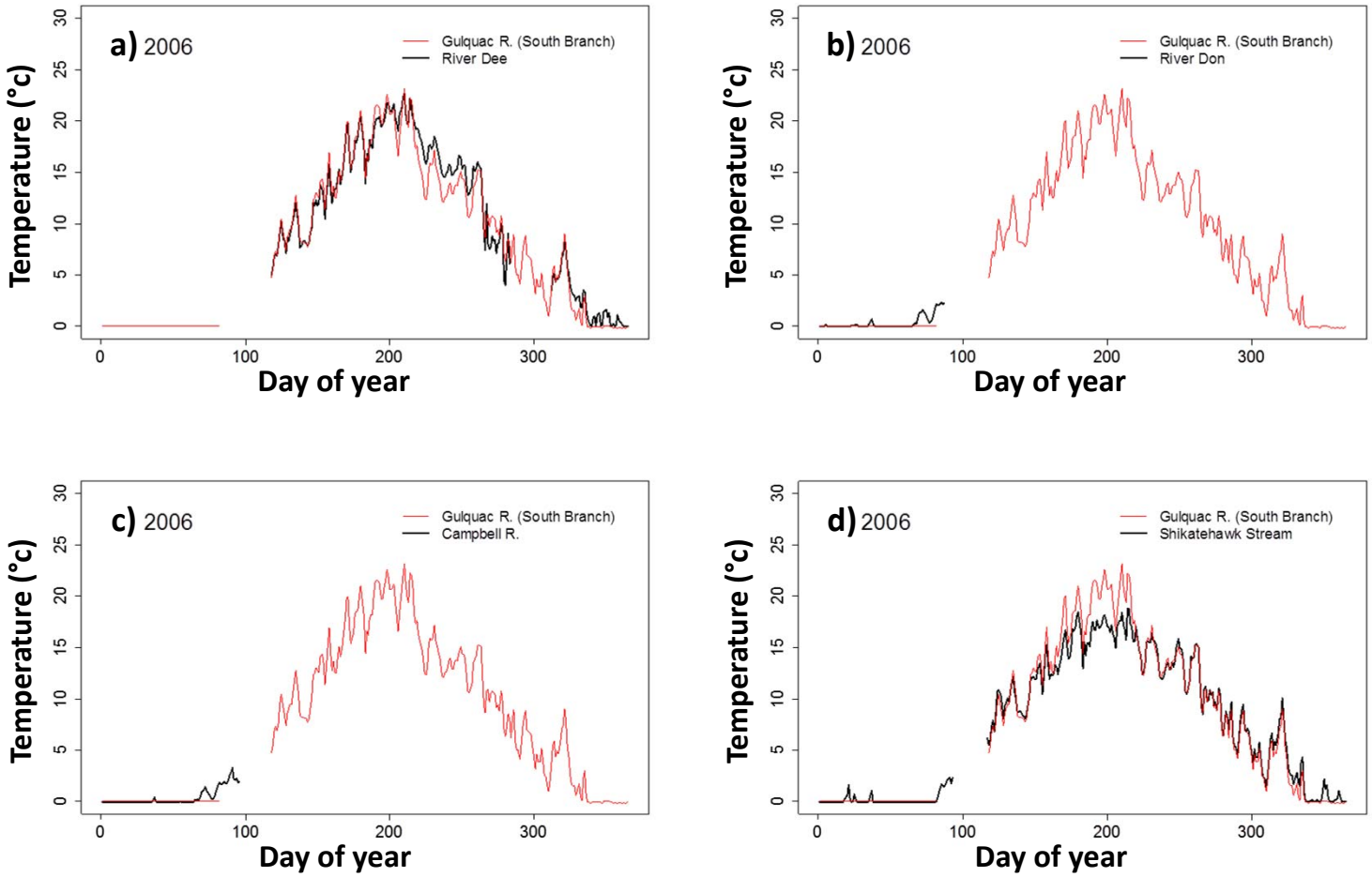

Figure A22. Comparison of daily mean values for 2006 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

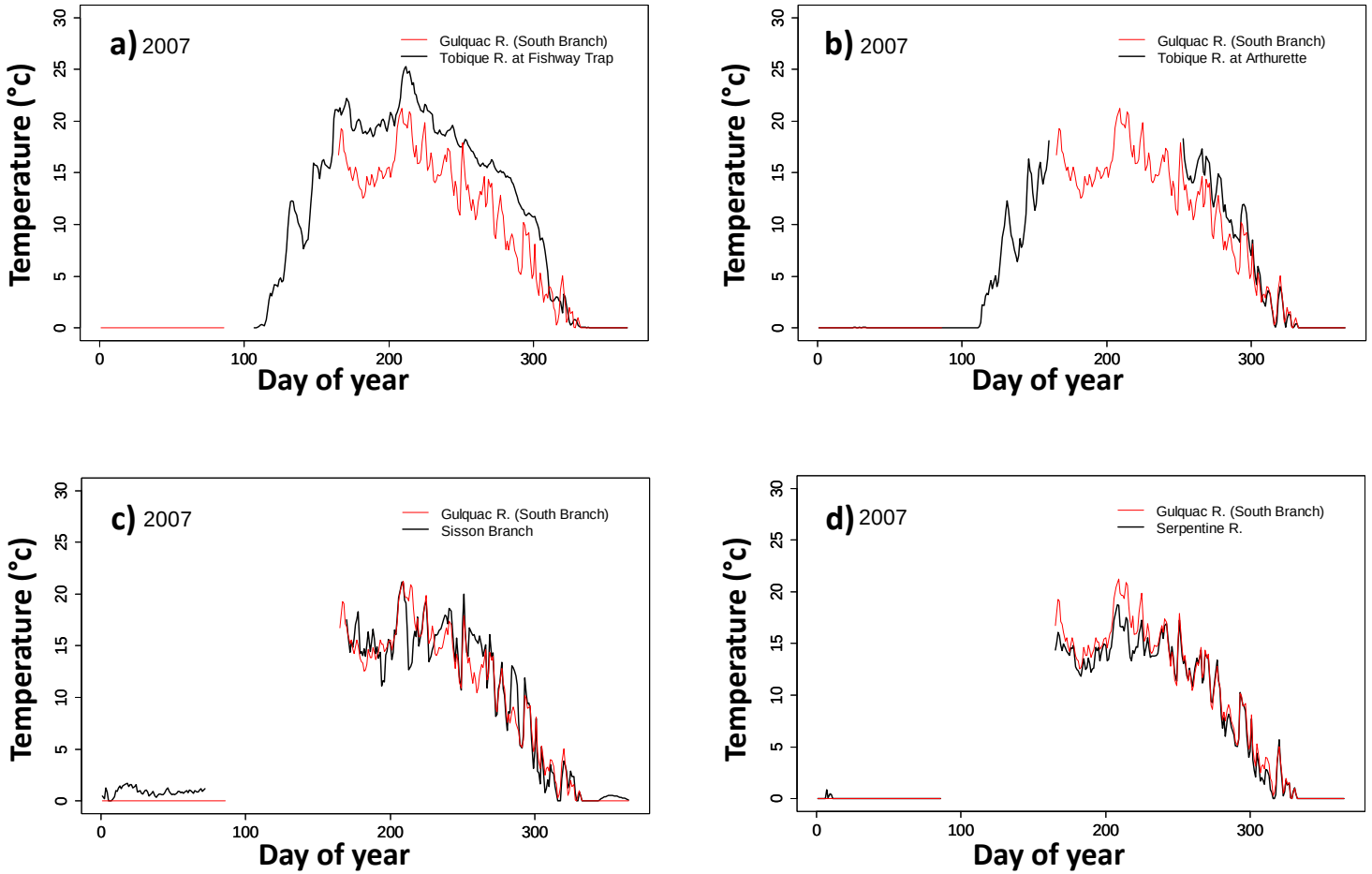

Figure A23. Comparison of daily mean values for 2007 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

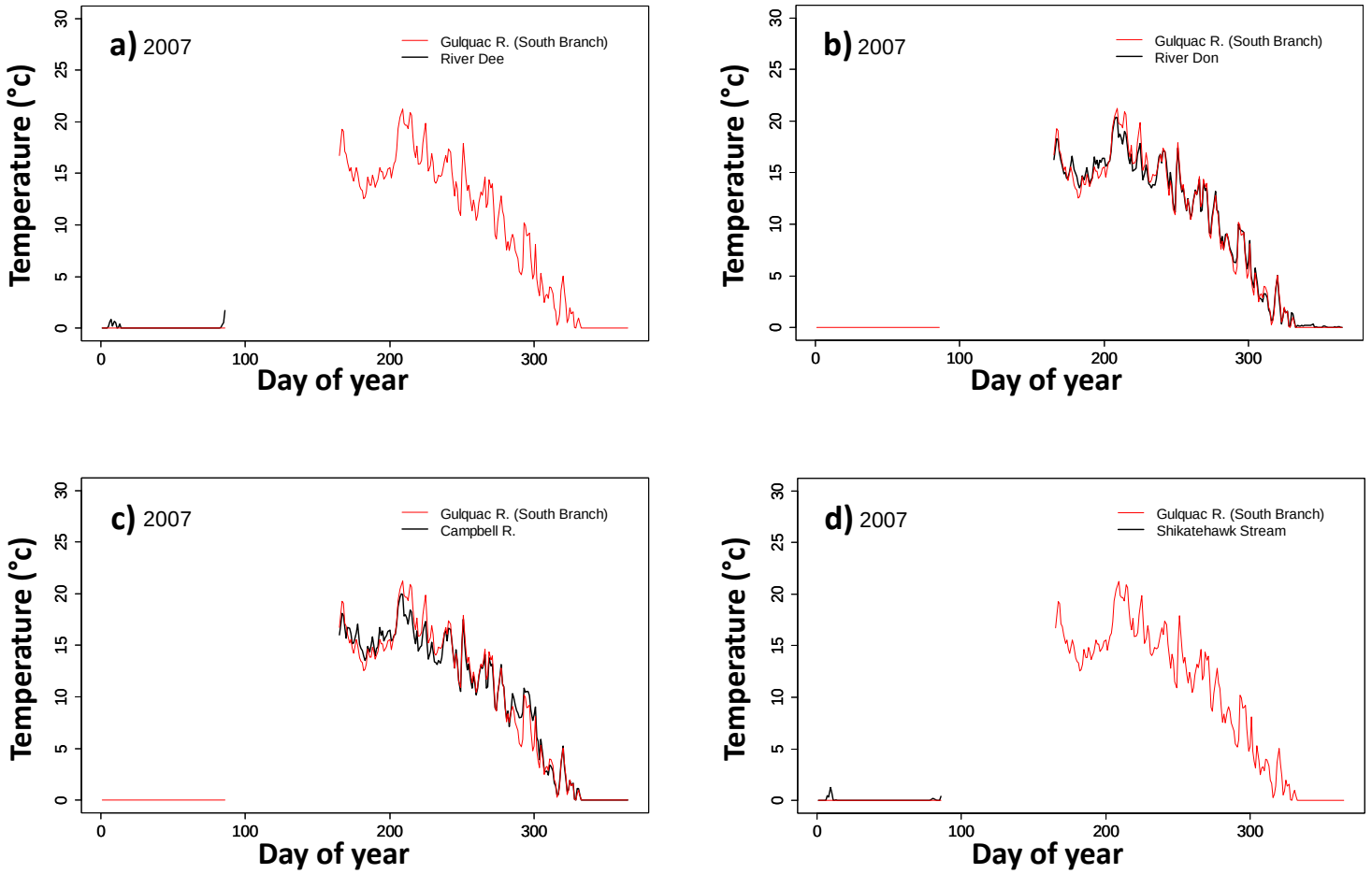

Figure A24. Comparison of daily mean values for 2007 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

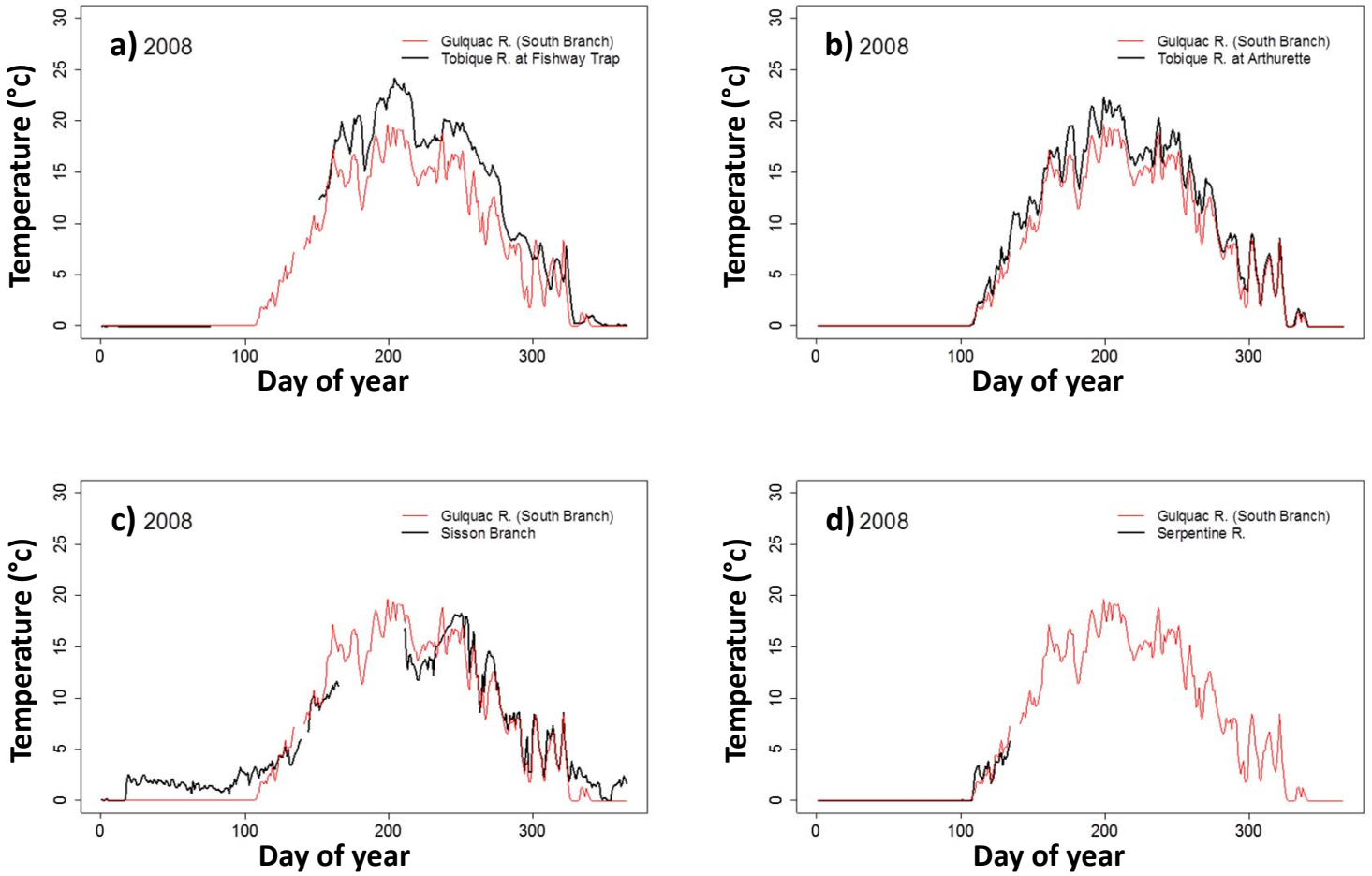

Figure A25. Comparison of daily mean values for 2008 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

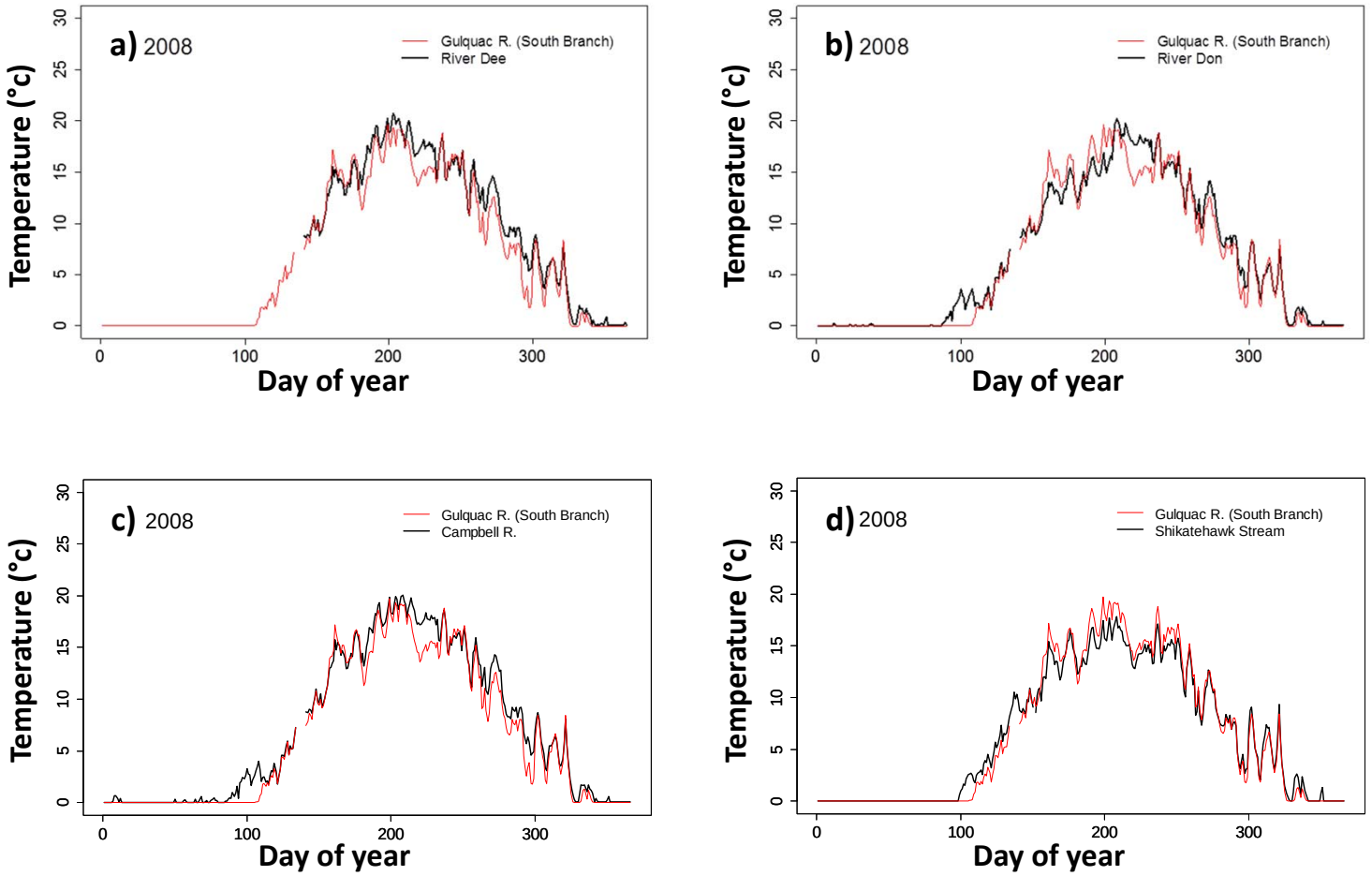

Figure A26. Comparison of daily mean values for 2008 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

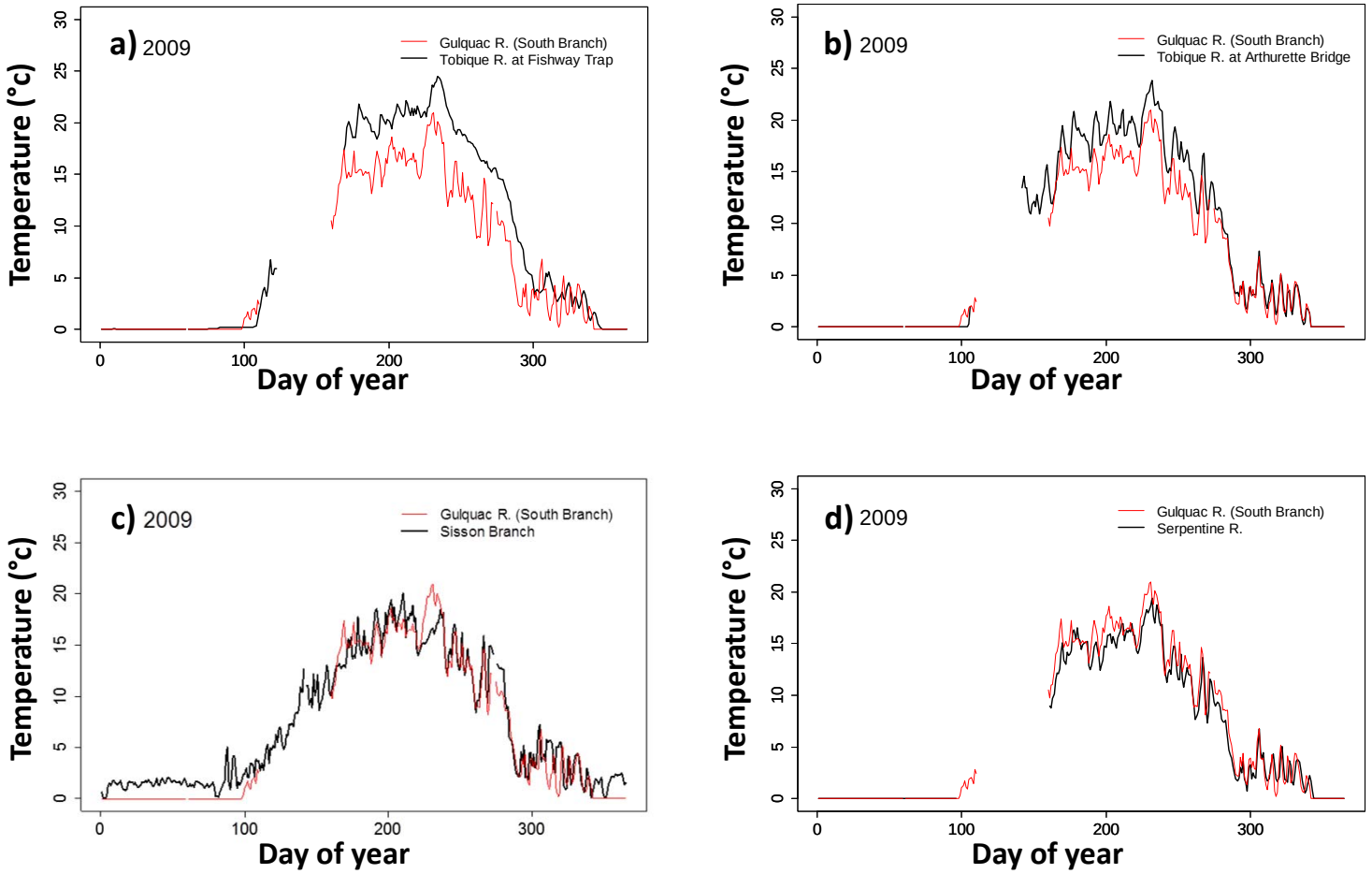

Figure A27. Comparison of daily mean values for 2009 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

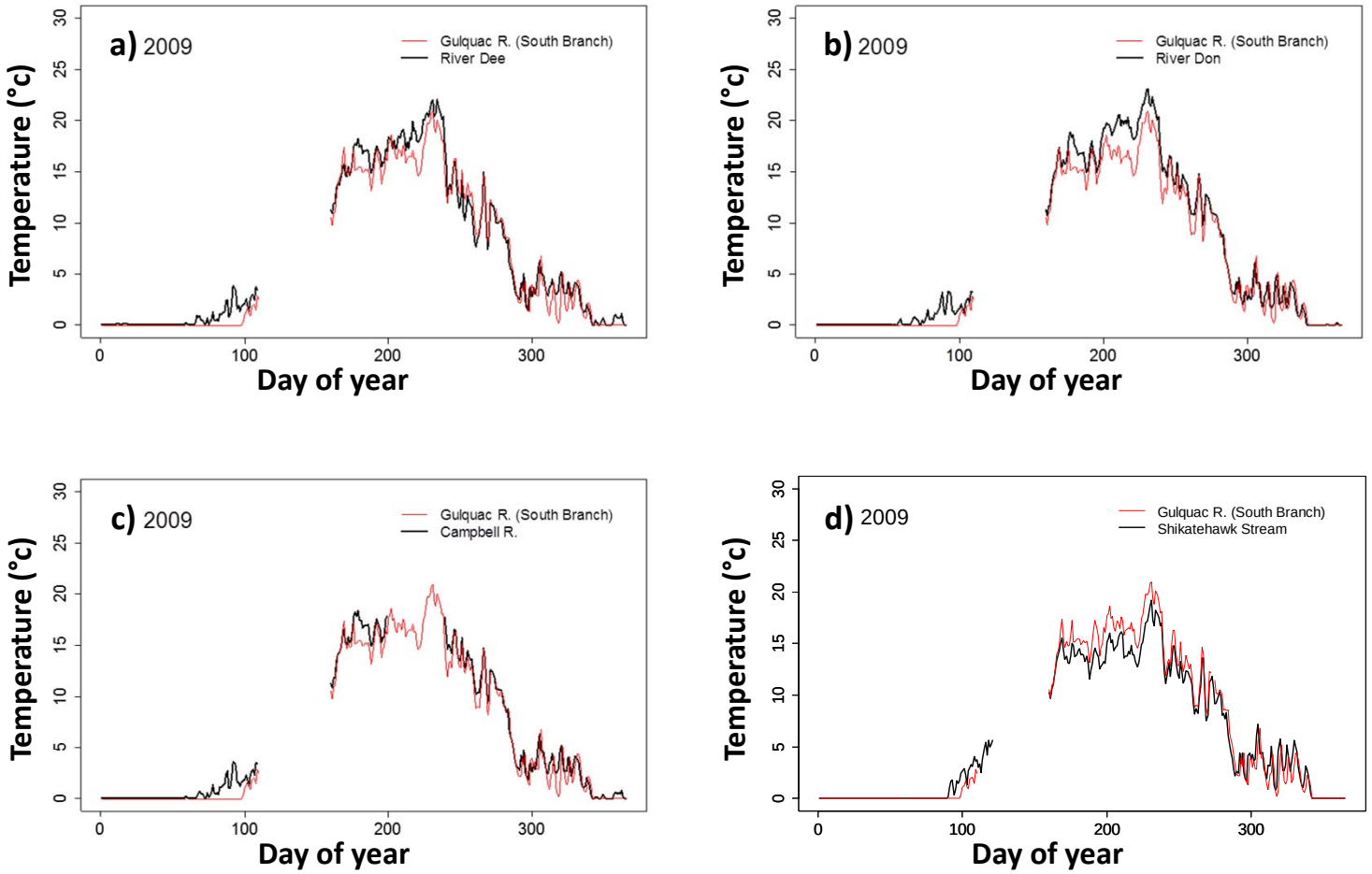

Figure A28. Comparison of daily mean values for 2009 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

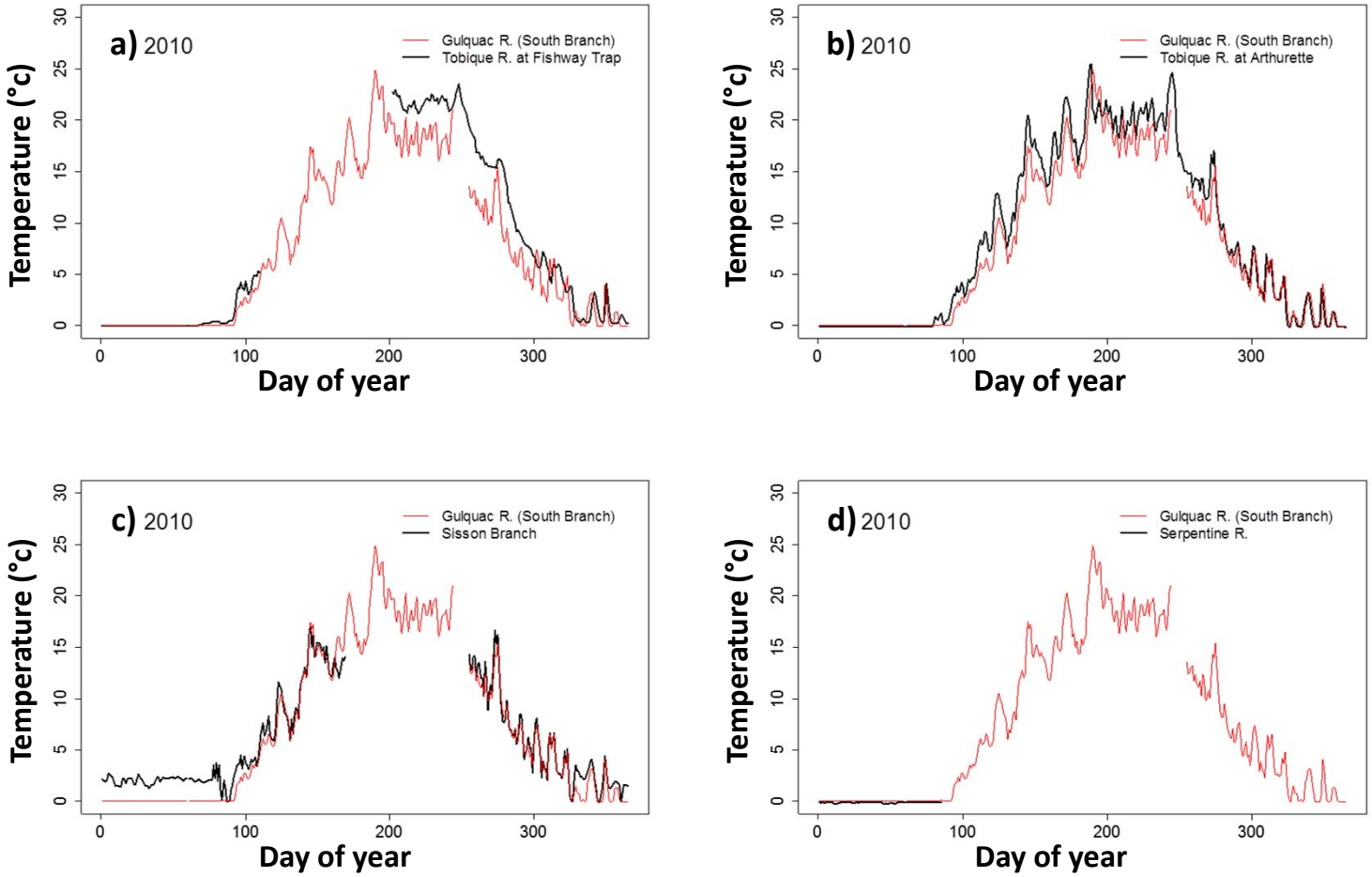

Figure A29. Comparison of daily mean values for 2010 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

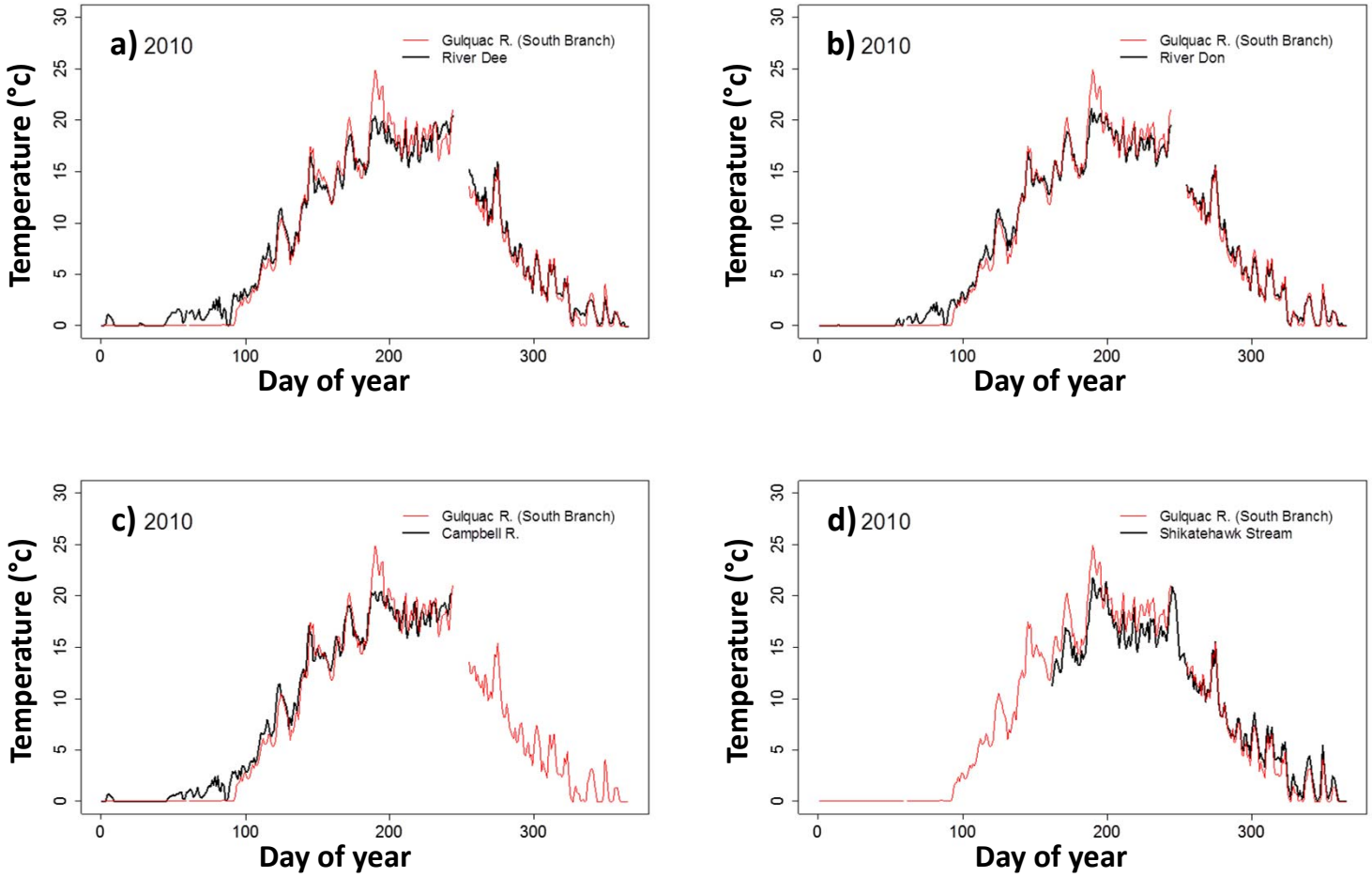

Figure A30. Comparison of daily mean values for 2010 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

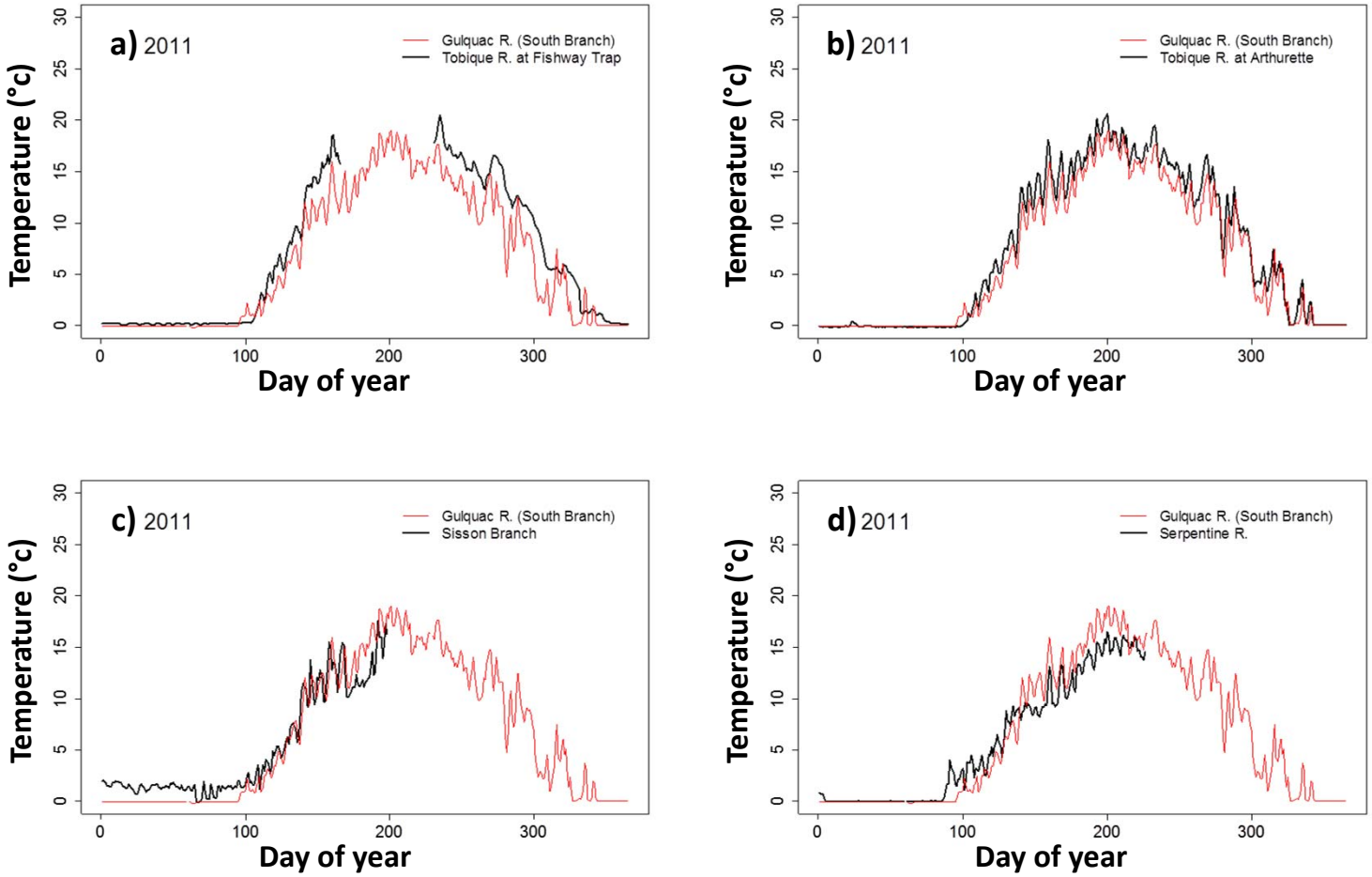

Figure A31. Comparison of daily mean values for 2011 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

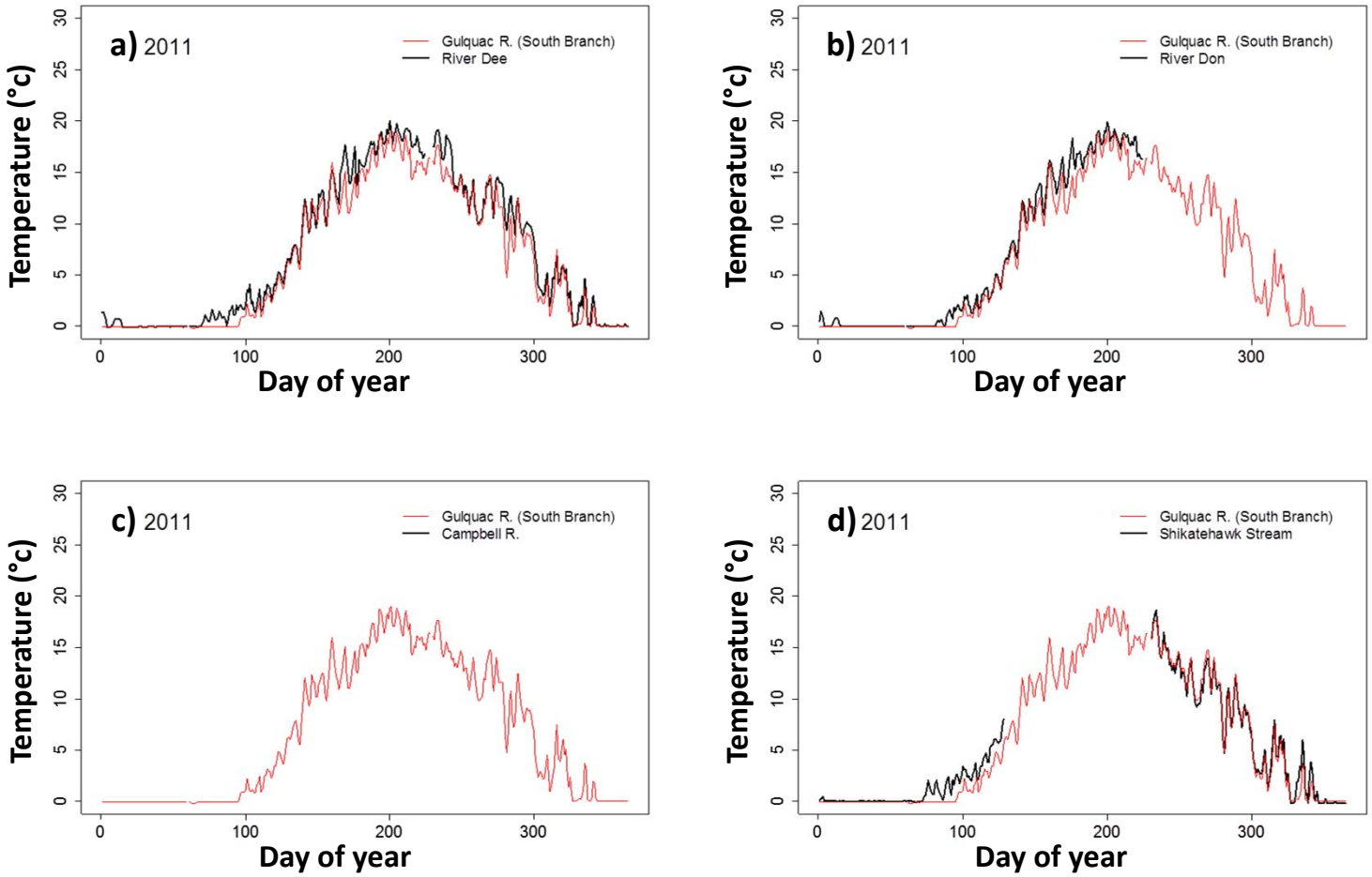

Figure A32. Comparison of daily mean values for 2011 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

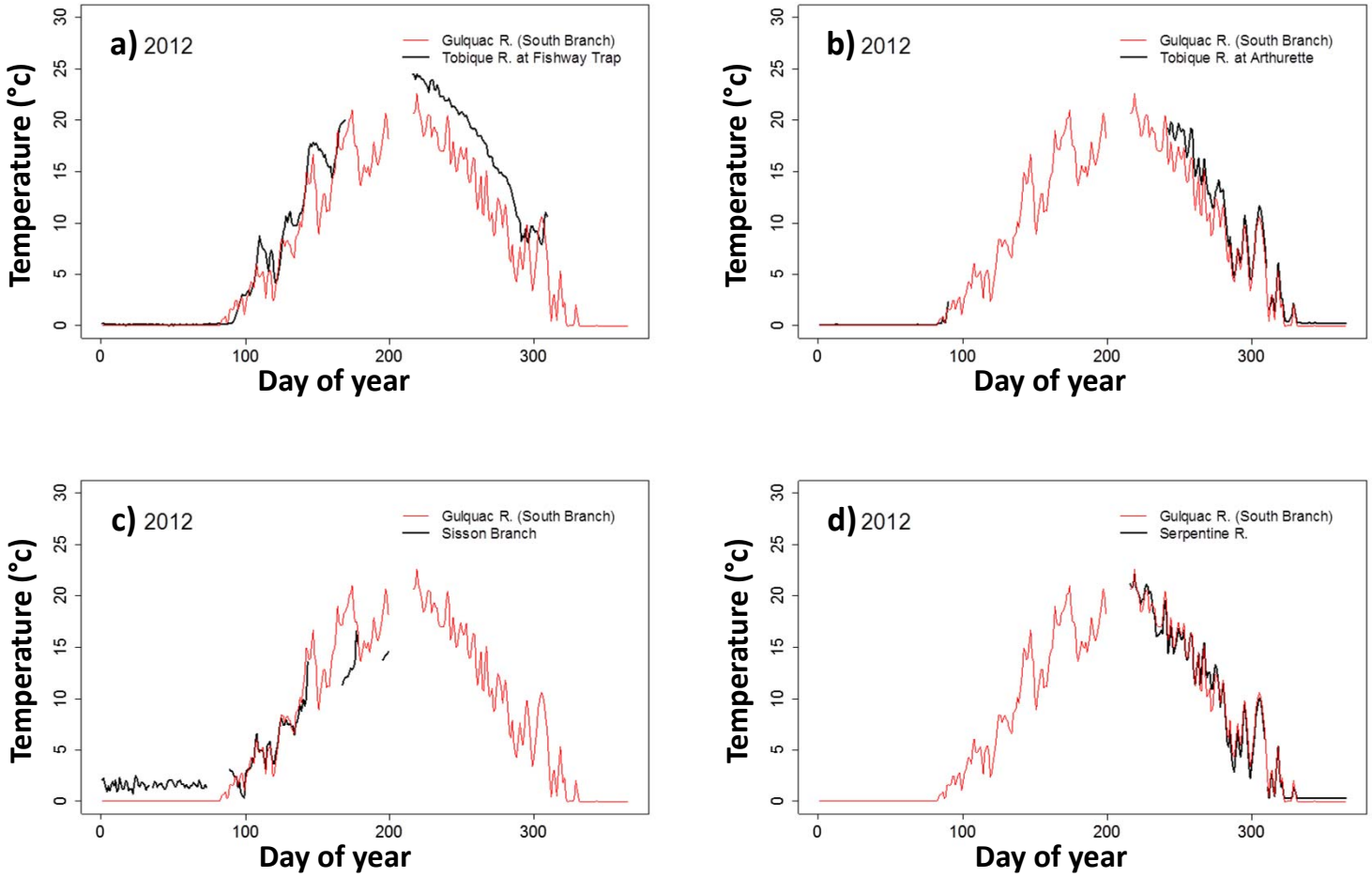

Figure A33. Comparison of daily mean values for 2012 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

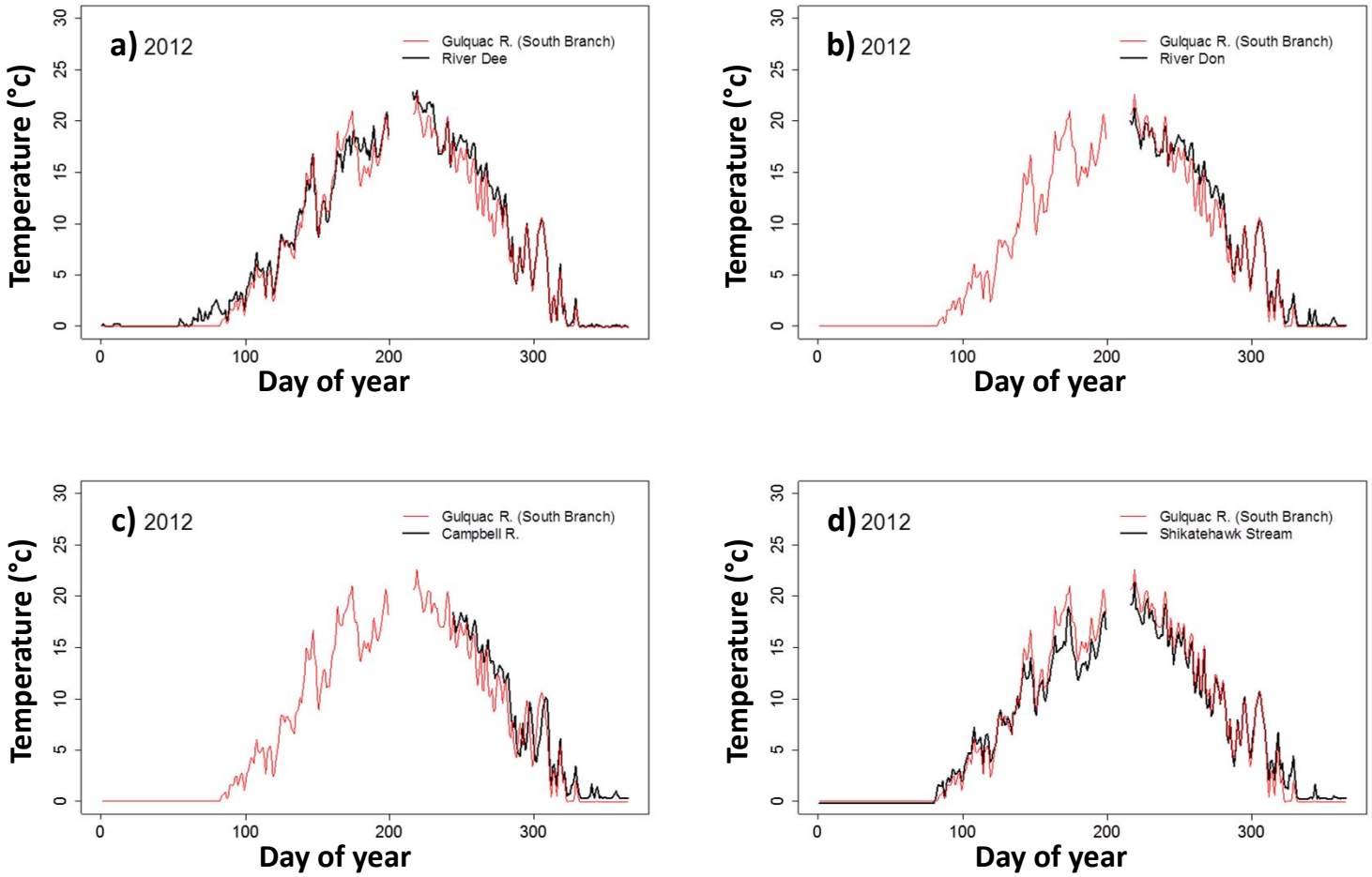

Figure A34. Comparison of daily mean values for 2012 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

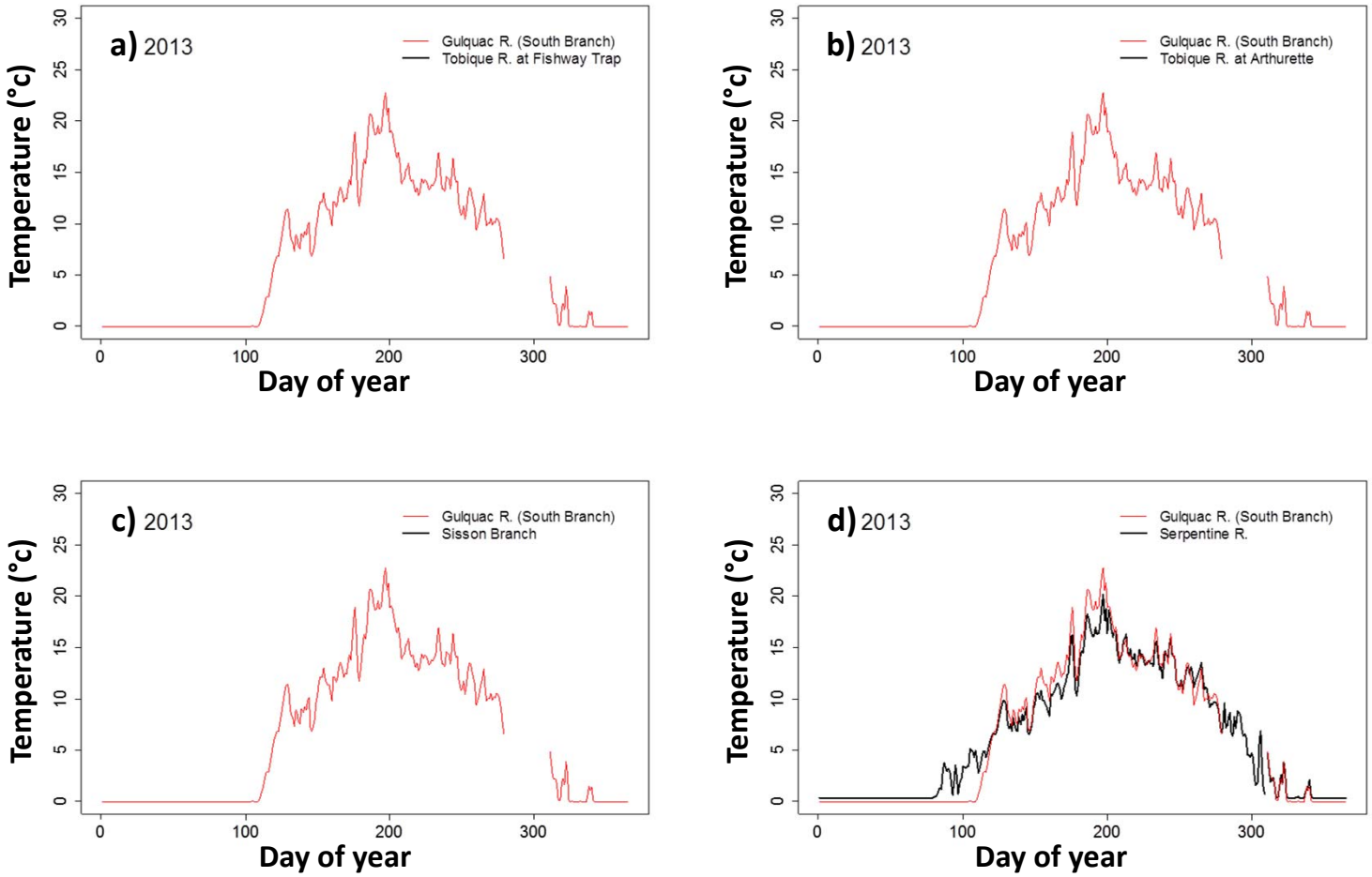

Figure A35. Comparison of daily mean values for 2013 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

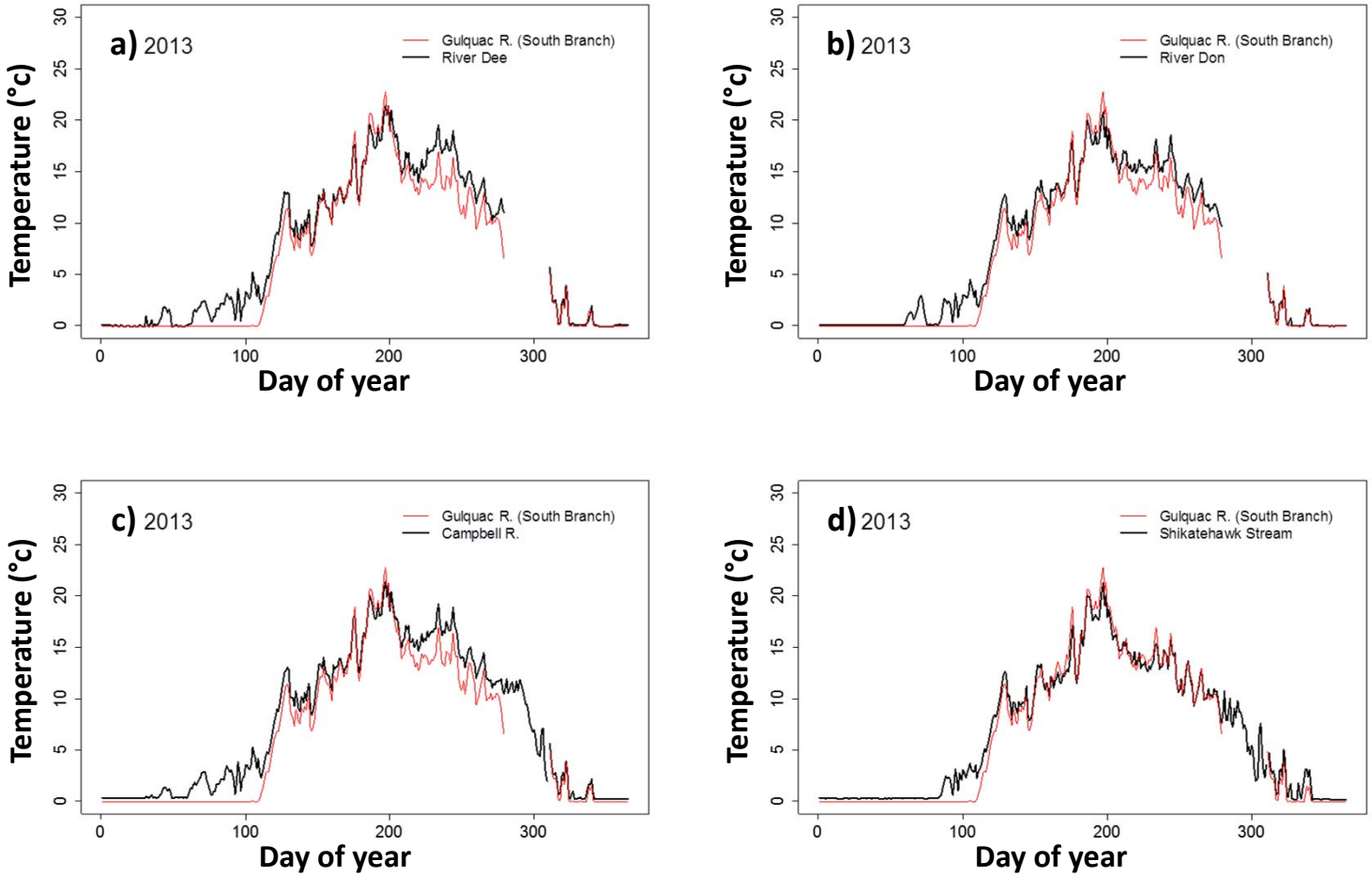

Figure A36. Comparison of daily mean values for 2013 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

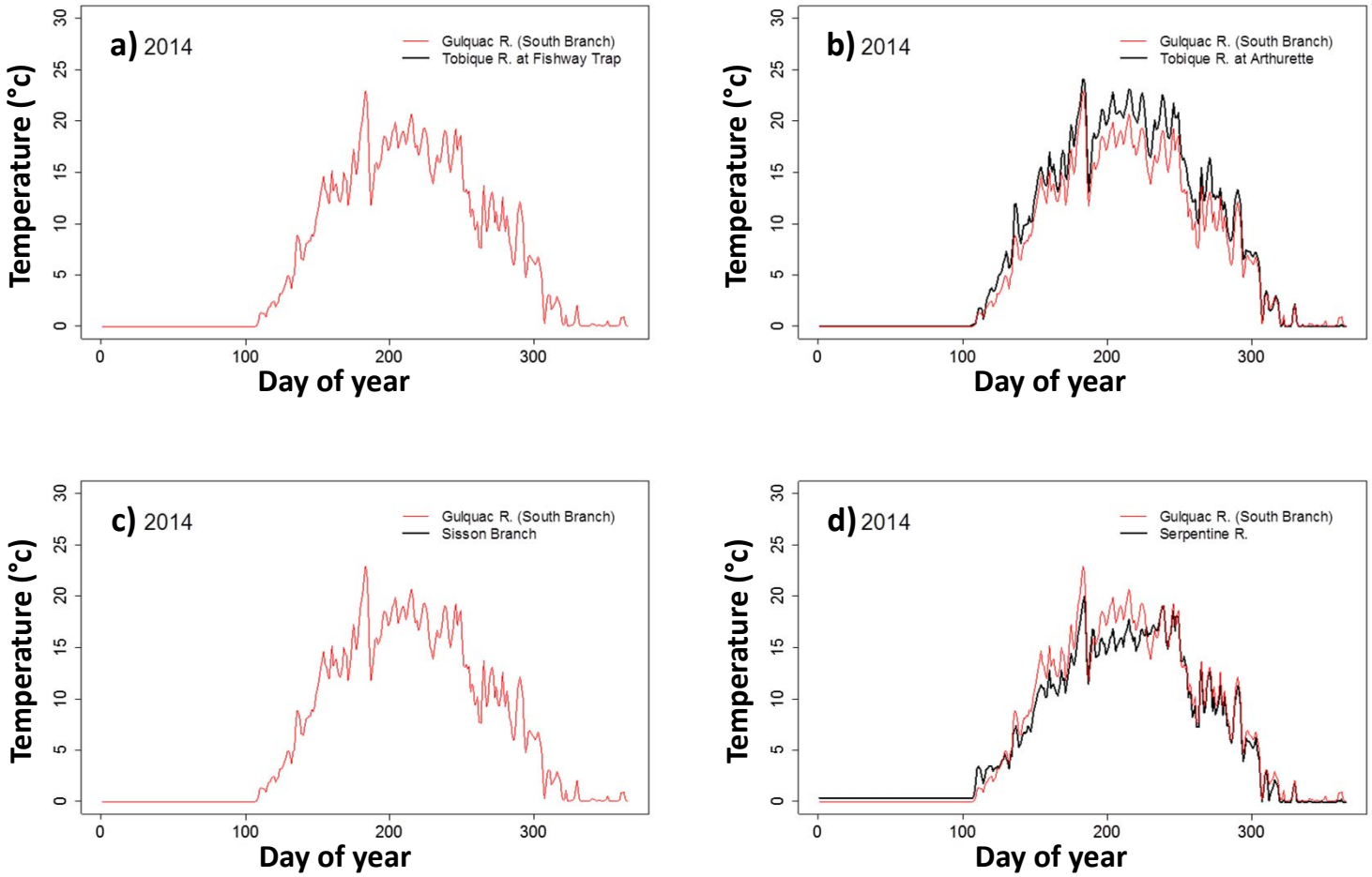

Figure A37. Comparison of daily mean values for 2014 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

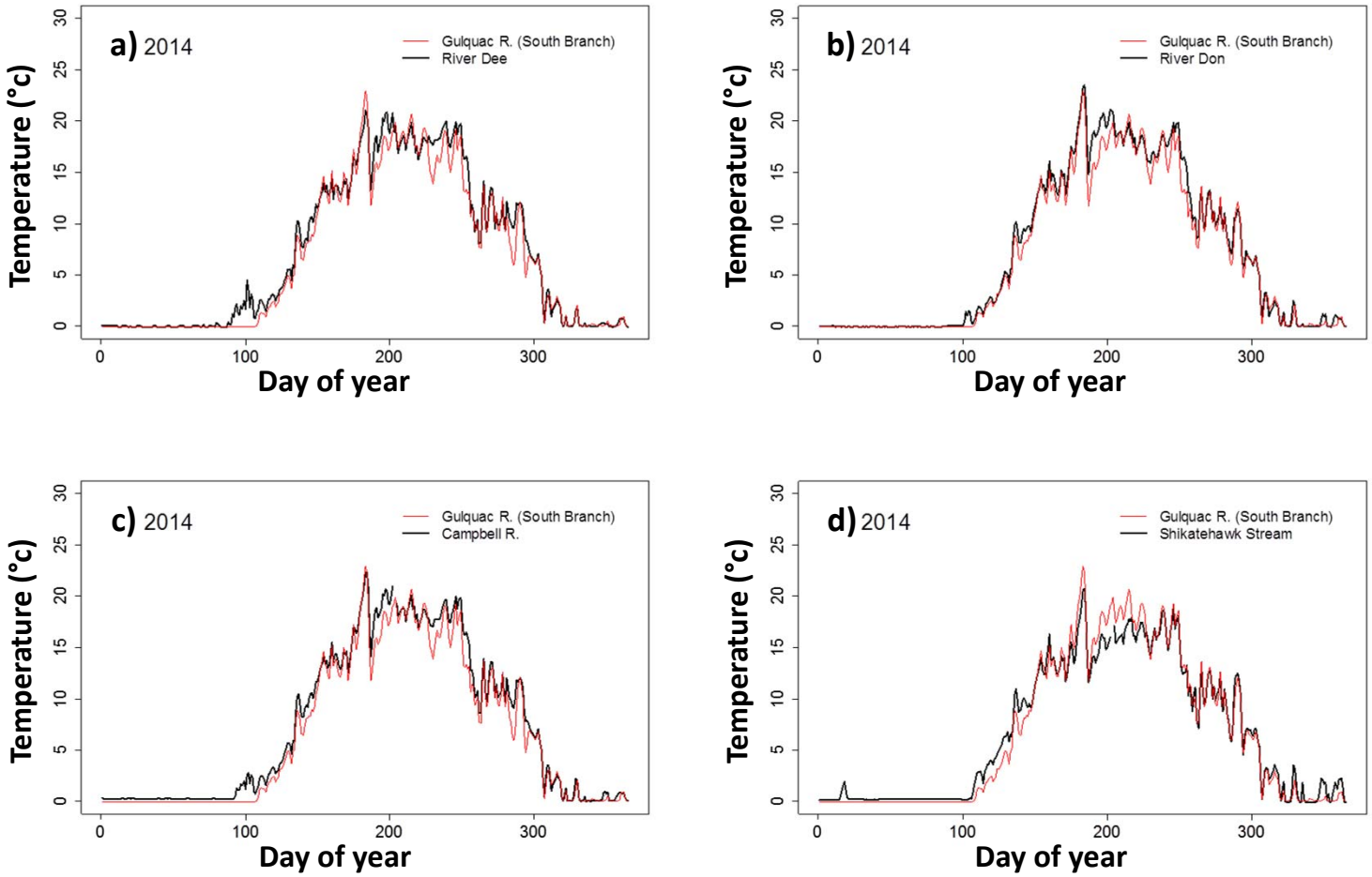

Figure A38. Comparison of daily mean values for 2014 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

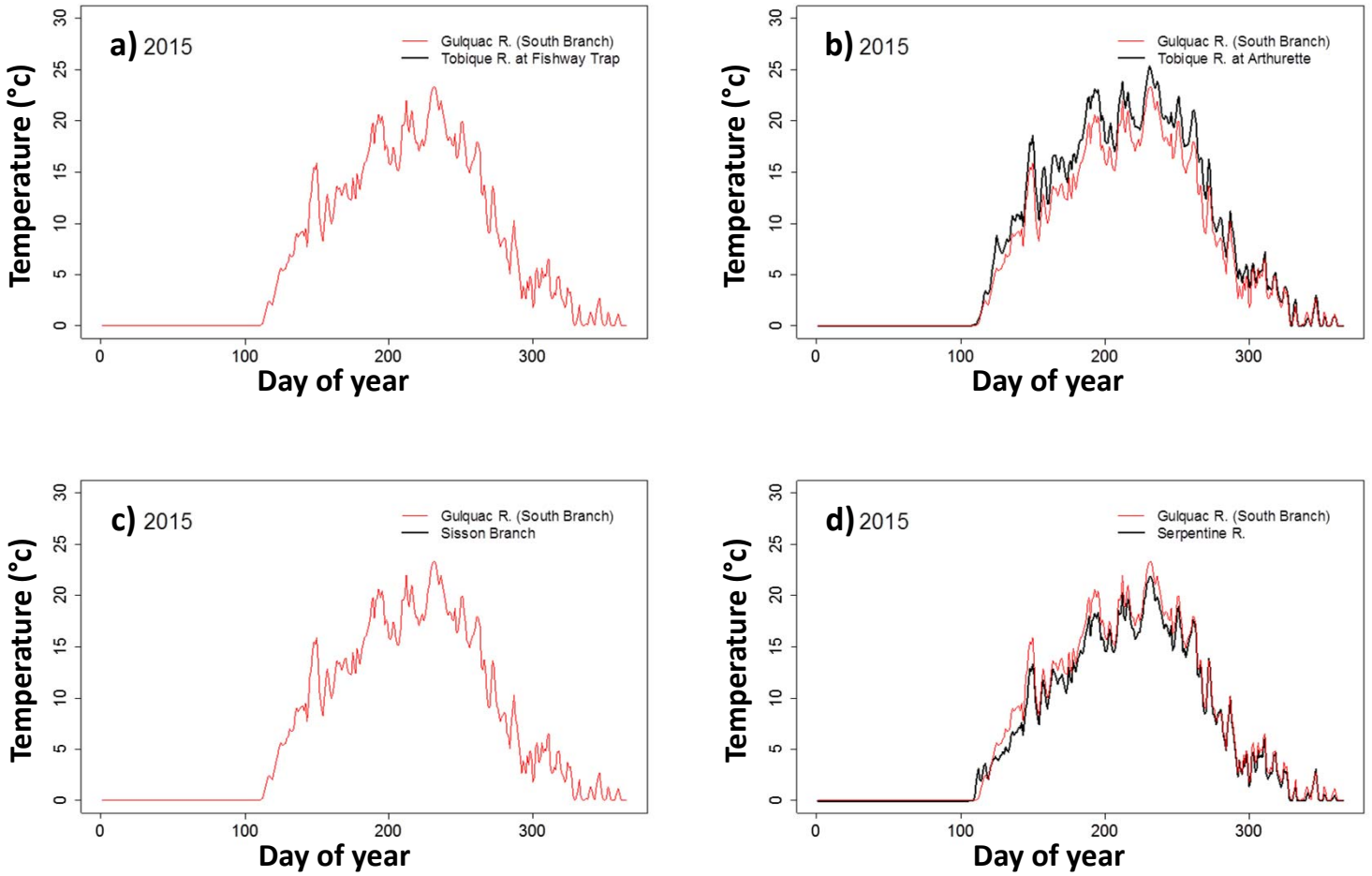

Figure A39. Comparison of daily mean values for 2015 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

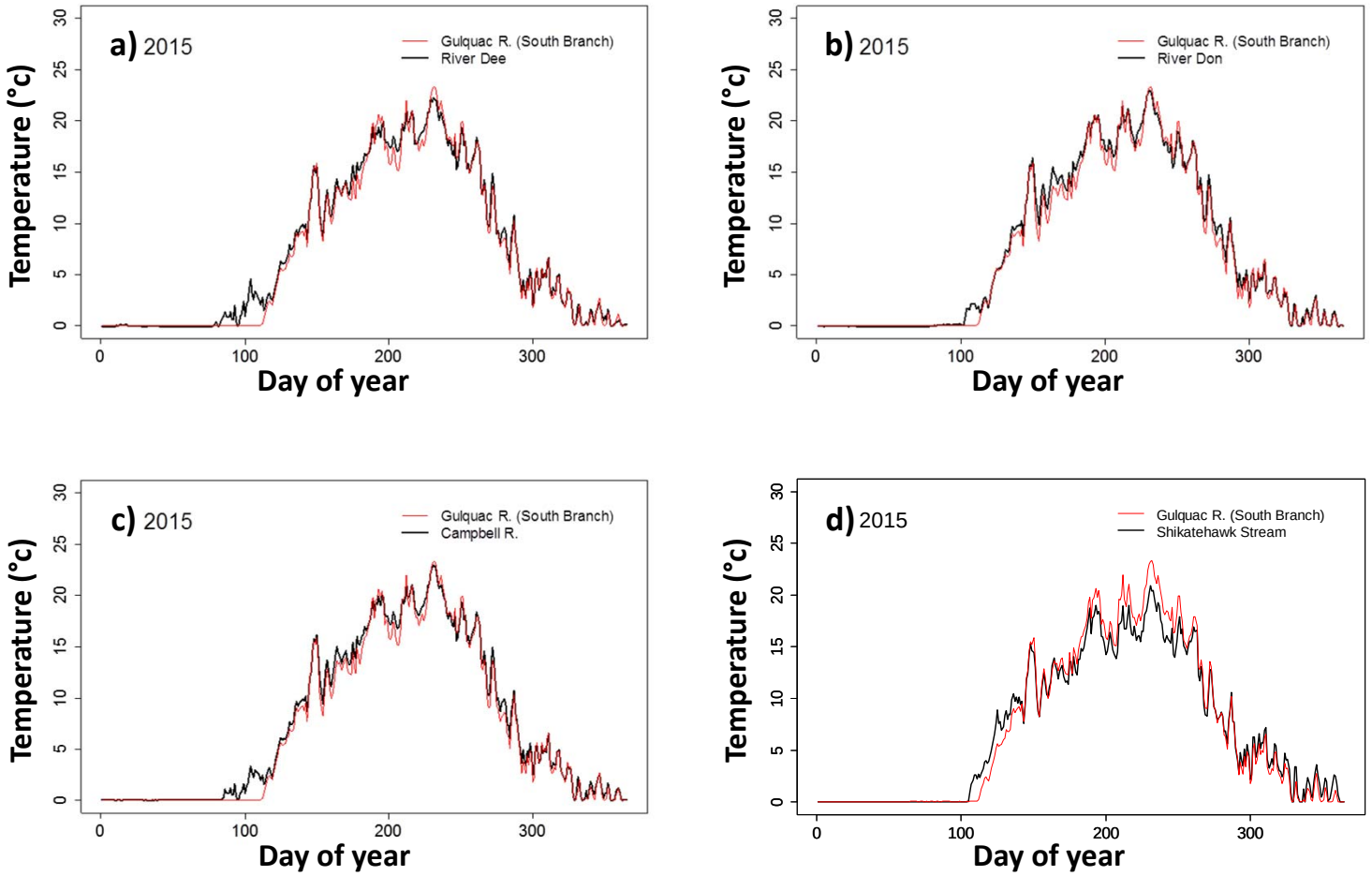

Figure A40. Comparison of daily mean values for 2015 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream

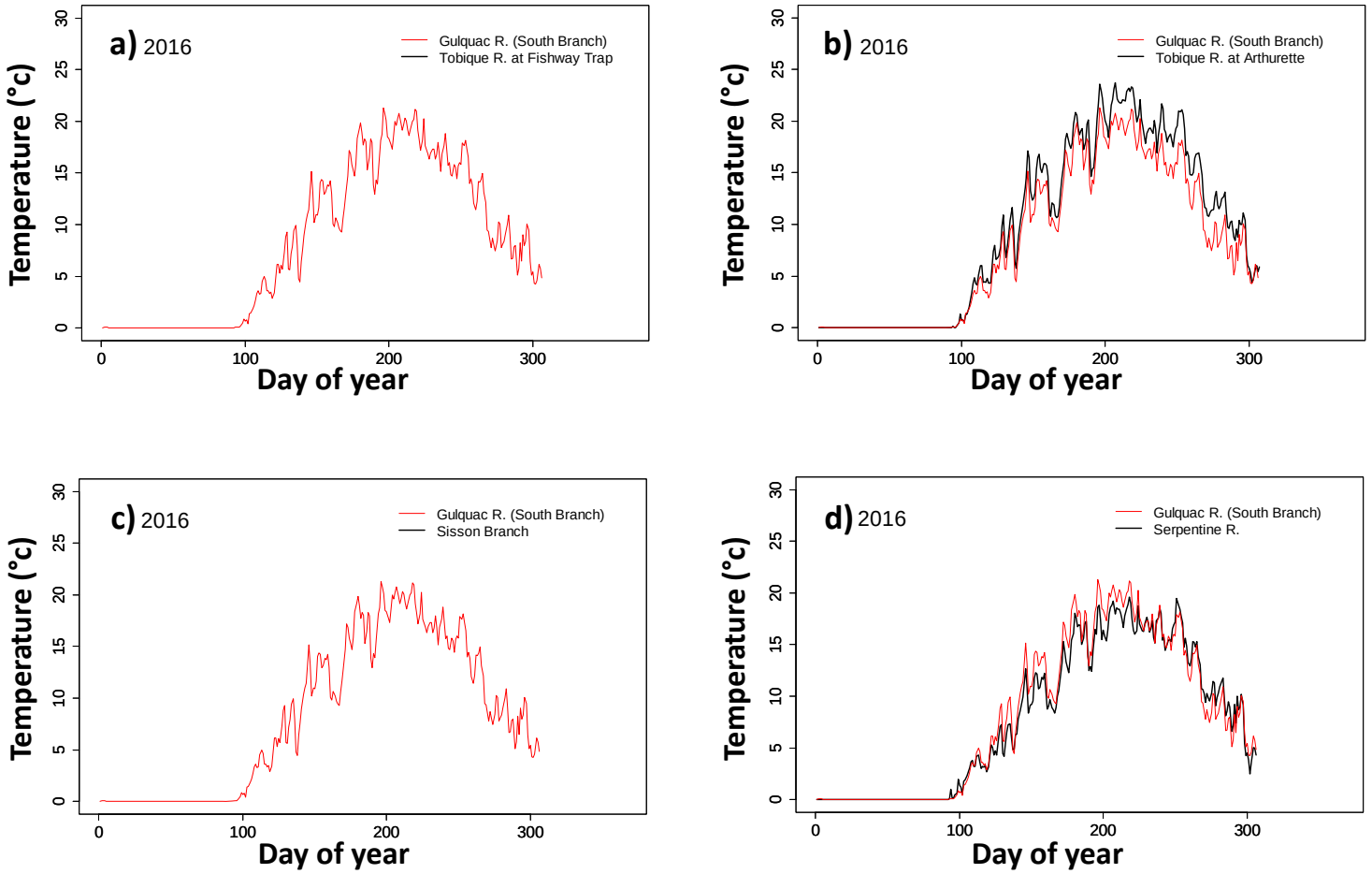

Figure A41. Comparison of daily mean values for 2016 between Gulquac River (South Branch) and a) Tobique River Fishway Trap, b) Tobique River Arthurette Bridge, c) Sisson Branch and d) Serpentine River

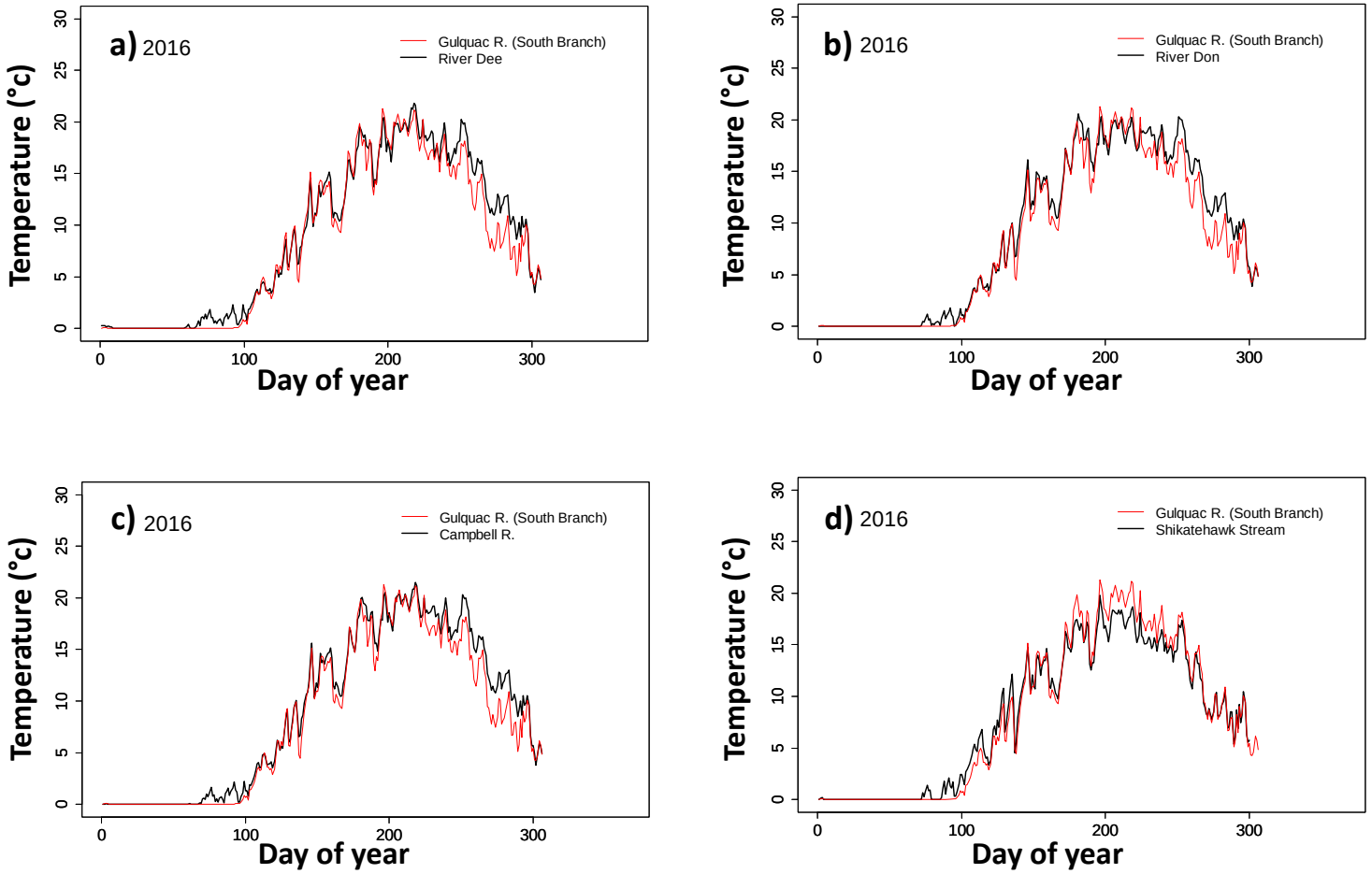

Figure A42. Comparison of daily mean values for 2016 between Gulquac River (South Branch) and a) River Dee, b) River Don, c) Campbell River and d) Shikatehawk Stream