Kolarctic CBC – Project KO4178; Conserving our Atlantic salmon as a sustainable resource for people in the North; fisheries and conservation in the context of growing threats and a changing environment.

REPORT I. Changing weather conditions, air temperature and precipitation, are driving annual and long-term changes in subarctic salmon environment and in the timing of salmon migrations in the River Tana watershed through air and water temperature synchrony

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Co-funded by the European Union

Statsforvalteren i Troms og Finnmark PB 700, 9815 VADSØ www.statsforvalteren/troms-finnmark/ CoASal – KO4178 project	ISBN 978-82-94021-00-0 Date: 31.1.2023

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Abstract

Mean monthly temperatures at Kevo Station within the Tana watershed, has increased since the early 2000s towards present years, despite the wide annual variations in the monthly mean air temperatures. This increase is obvious in the spring months April and May and in the late summer months, August and September. Annual variations are also smaller in the latest years compared to the measurements taken in 1960's and 1970's, in almost all the months. Monthly mean temperature deviations during the last 15-20 years in April, May, August and September indicates abnormal warmer periods compared to earlier decades.

The highest monthly air temperature values in the River Tana valley, has in the latest years taken place especially in July, August, September and in October. Water levels and discharges are normally at its lowest in July. Water temperatures generally follows the air temperature fluctuations in small brooks and in large tributaries each hour throughout the entire day. The synchrony is observed especially from June to the end of September when the melting snow in the mountains does not affect water temperatures. Clearly, River Tana water temperatures in the summer increases if air temperatures are rising. For example, in the year 2018 air temperature in Kevo station reached 32 °C and affected the River Tana water to increase to close to 25 °C. These surprising increases in water temperatures might cause disease outbreaks, cessations in salmon migrations towards spawning grounds, and salmon might migrate back to seawater or to deep pools where there is a risk of being overexploited in gillnet fisheries. When the water is too warm, salmon does not bite lures, flies etc. and therefore rod fishery is fruitless. In too warm water, juvenile salmon lose their territorial behavior, their appetite and ceases its feeding. They start to move in schools and are moving from riffles to slow flowing pools. When they move from their ordinary territorial site to secondary habitats, they are more exposed to predation.

The ascend of small salmon (one sea winter fish) into the northern rivers happens simultaneously. Abnormal low water level together with simultaneous high air temperatures is making water temperatures too warm for salmon and therefore salmon migration into the rivers or migrations within the rivers can be ceased. High water temperatures and simultaneously low water levels has negative effects on the rod fishery. Very low water levels, however, can make fishing with gillnets and weirs very effective in the River Tana watershed.

Daily water temperatures in the River Tana have exceeded 15°C in recent decades more frequently than in 1960's. The warmest water temperatures (up to 25°C) have been measured in

the River Tana during the last years. Since the year 2000, when water temperatures in October have reached 0°C, it has stayed close to 0°C until early or middle May the following year. In the River Tana ice breaking-up takes place most frequently in the period from early May to May 20^{th} and, in some few years very late in May. Depending on the ice breaking-up dates, water temperatures increase towards to the end of May. Early ice breaking-up dates results with up to 10°C water temperatures in the end of May.

The River Tana with its tributaries and brooks are usually covered by ice from the end of October or November to the middle of May. Figure 54 indicates the wide time period when ice breaking- up has taken place. Some few years ice breaking-up has happened in the end of April or even early in June.

Ice breaking-up dates in the Levajohka site has nowadays taken place earlier than in the end of the year 1880, although there have been huge annual variations. Earlier ice breaking-up has also been observed in another large northern river, Torniojoki, where data is available from 1750's and onwards. Nowadays it has been found that the exact ice breaking-up day has been difficult to observe because ice melting in the rivers has behaved differently compared to years when ice has been thick.

The date of the ice break-up has had great impact to the median date of salmon capture in the River Tana mainstream and if the median date arrives earlier or later than normal. Especially the three sea-winter salmon is affected, but slightly also the two sea-winter salmon. Large three sea winter salmon is normally ascending at earliest, late in the spring and early in summer, into the River Tana. Therefore, the ascend period of this large salmon into the River Tana is responding into the ice break-up dates; late ice break-up results in a late run. Smaller salmon, like one sea winter salmon ascends into the River Tana mainly very late in June and the whole July month and ice melting period doesn´t determine their migration period. If ice break- up dates continue to take place earlier and earlier in the coming years due to global temperature changes it might reflect to the earlier ascend of large salmon. An earlier ascend of this large salmon means that they will be exploited in the river fishery for a longer period compared to years with late ice-break up.

Key words:
Atlantic salmon, Salmo salar, Tana, temperature changes, salmon migration, ice breake-up

Front page photo:
Eero Niemelä

Content

1. Air temperatures at the Kevo Station, Utsjoki, in the River Tana /Teno watershed

Air temperatures and other weather parameters has been followed in Kevo meteorological station (Utsjoki) since 1962 by the Finnish Meteorological Institute. Through the EU Kolarctic project KO4178 (CoASal), open environmental data has been collected to make graphical summaries which illustrate large annual and seasonal variations in both air and running water temperatures.

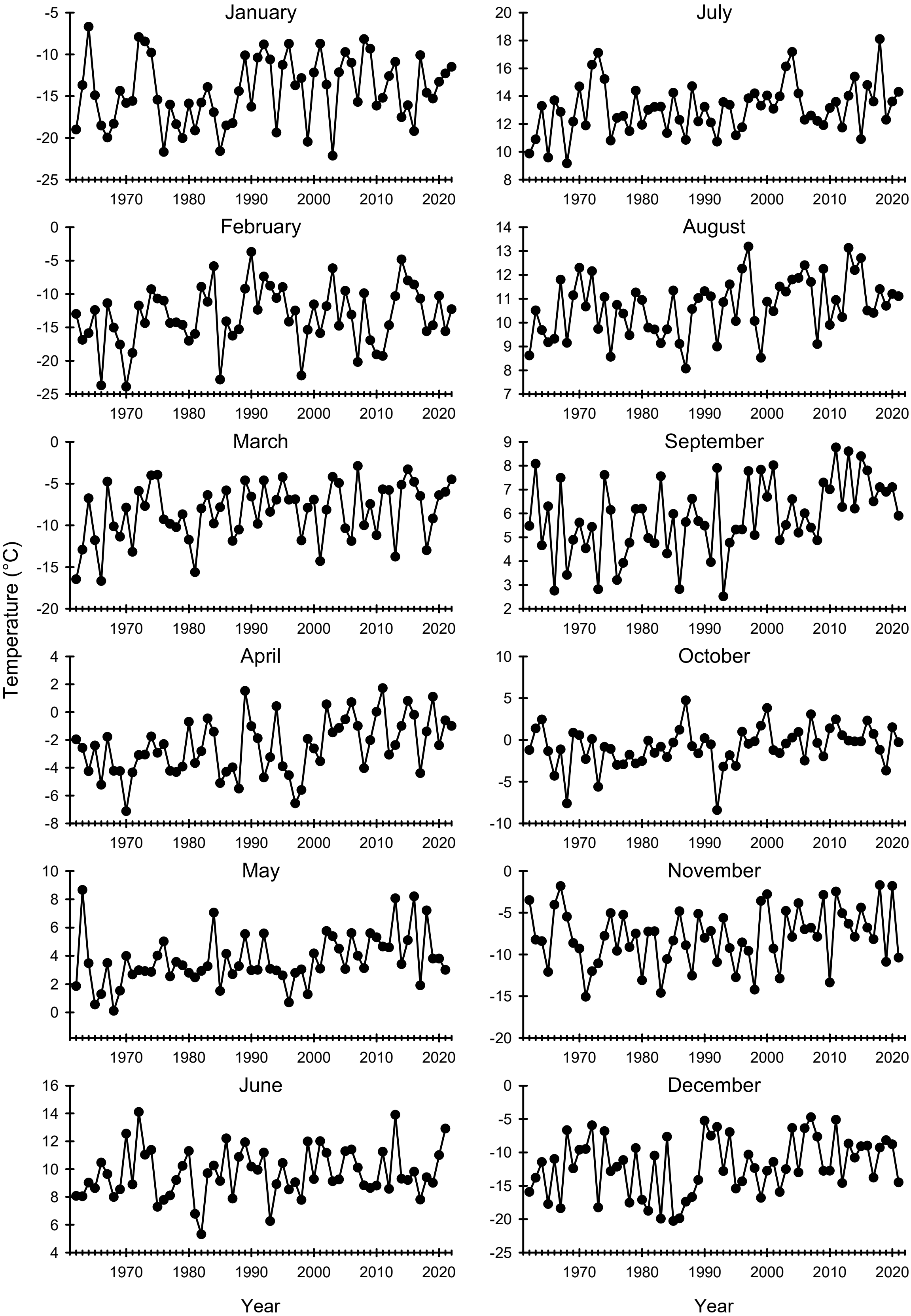


Figure 1. Monthly mean air temperatures at Kevo Station within Tana watershed. Source; Finnish Meteorological Institute.

Despite the wide annual variations in the monthly mean air temperatures, it is possible to observe increased mean monthly temperatures towards present years, since the early 2000s (Fig. 1). This increase is obvious in the spring months April and May and in the late summer months, August and September. Annual variations are also smaller in the latest years compared to the measurements taken in 1960's and 1970's, in almost all the months. The long-term mean annual air temperature has been below 0 °C but during the last 10 years it has been more generally above 0 °C. The increase in the mean annual air temperature started approx. in the beginning of 1990's (Fig. 2)

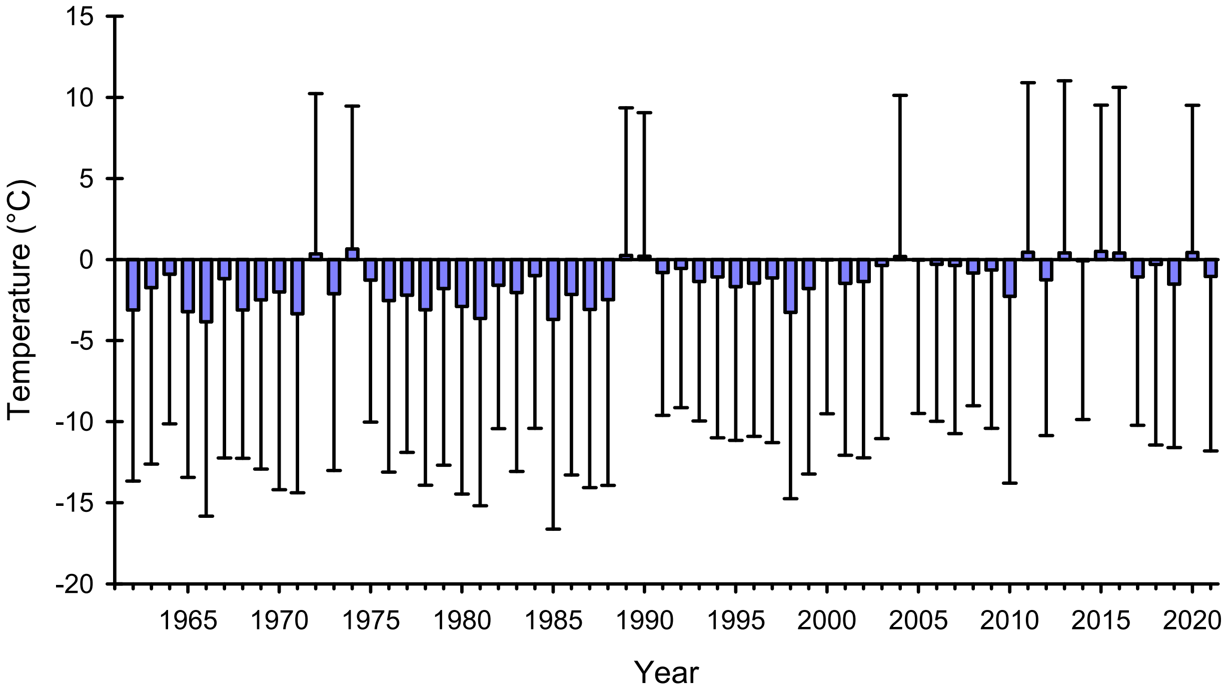


Figure 2. Annual mean air temperatures (SD) at Kevo Station within Tana watershed. Calculated from the mean monthly values. Source; Finnish Meteorological Institute.

Notwithstanding the fact that the mean annual air temperatures have been below 0 °C for a long time (Fig. 2), the mean summer temperatures (May, June, July, August, September) have been above 0 °C in all the years 1962-2021. In the long-term the highest mean summer temperatures have been in July reaching close to 15 °C and the coldest winter temperatures have been close -15 °C (Fig.3).

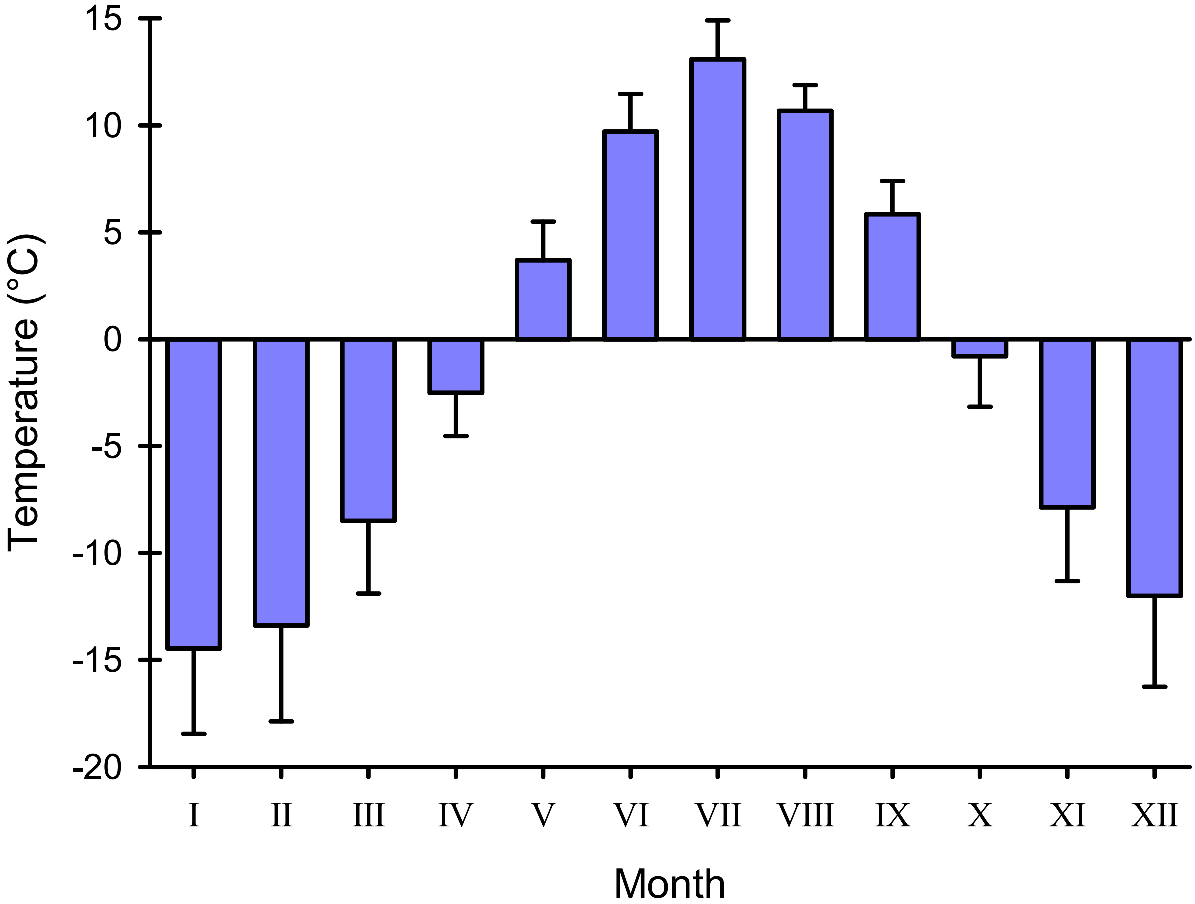


Figure 3. Monthly mean air temperatures (SD) at Kevo Station within Tana watershed. Calculated from the mean monthly values in the years 1962-2021. Source; Finnish Meteorological Institute.

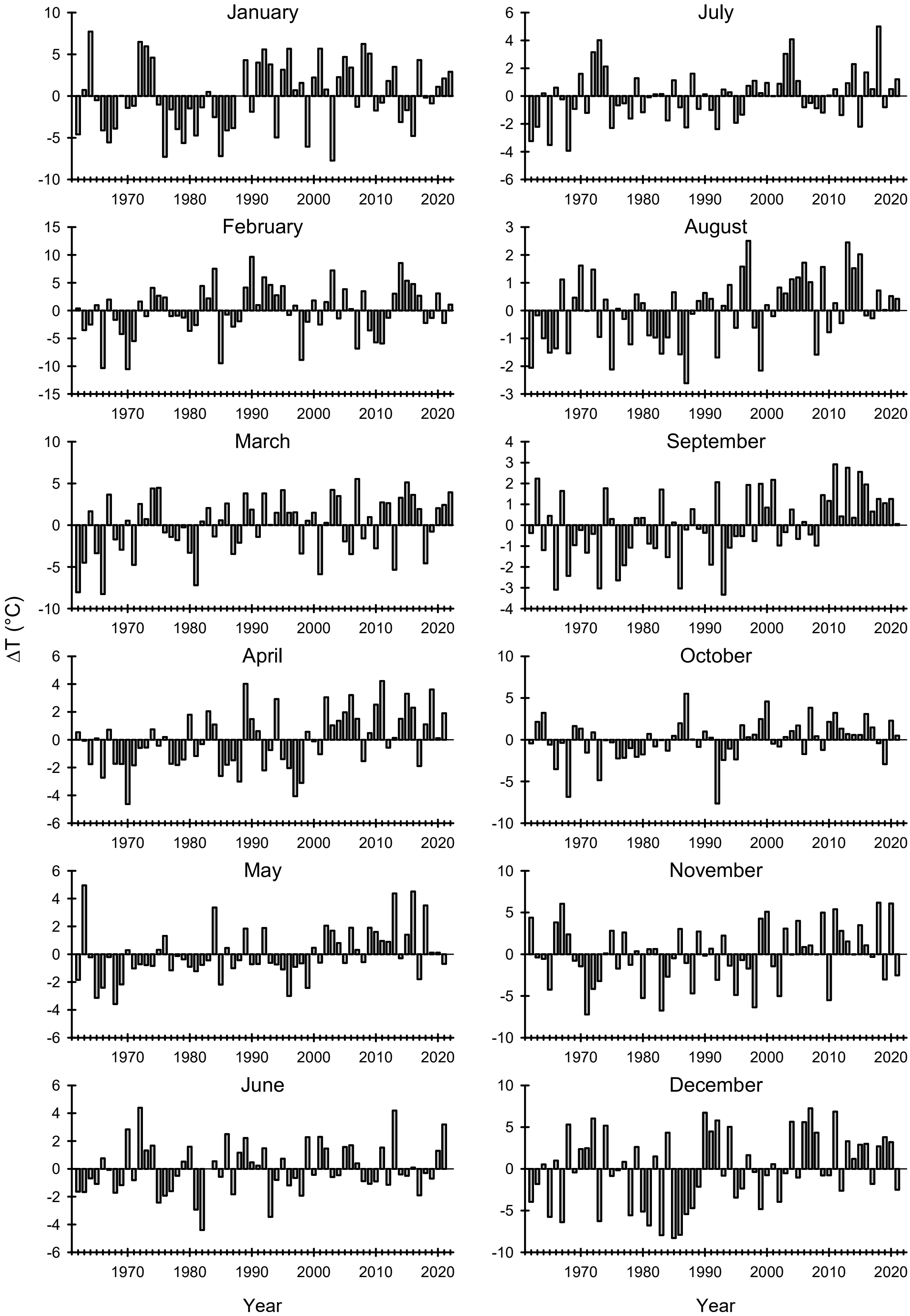


Figure 4. Monthly deviations from the long-term monthly mean air temperatures at Kevo Station in Tana watershed. Source; Finnish Meteorological Institute.

Monthly mean temperature deviations are indications of periods when temperatures have been clearly warmer or colder. For example, the deviations in April, May, August and September indicates abnormal warmer periods compared to earlier decades during the last 15-20 years (Fig. 4).

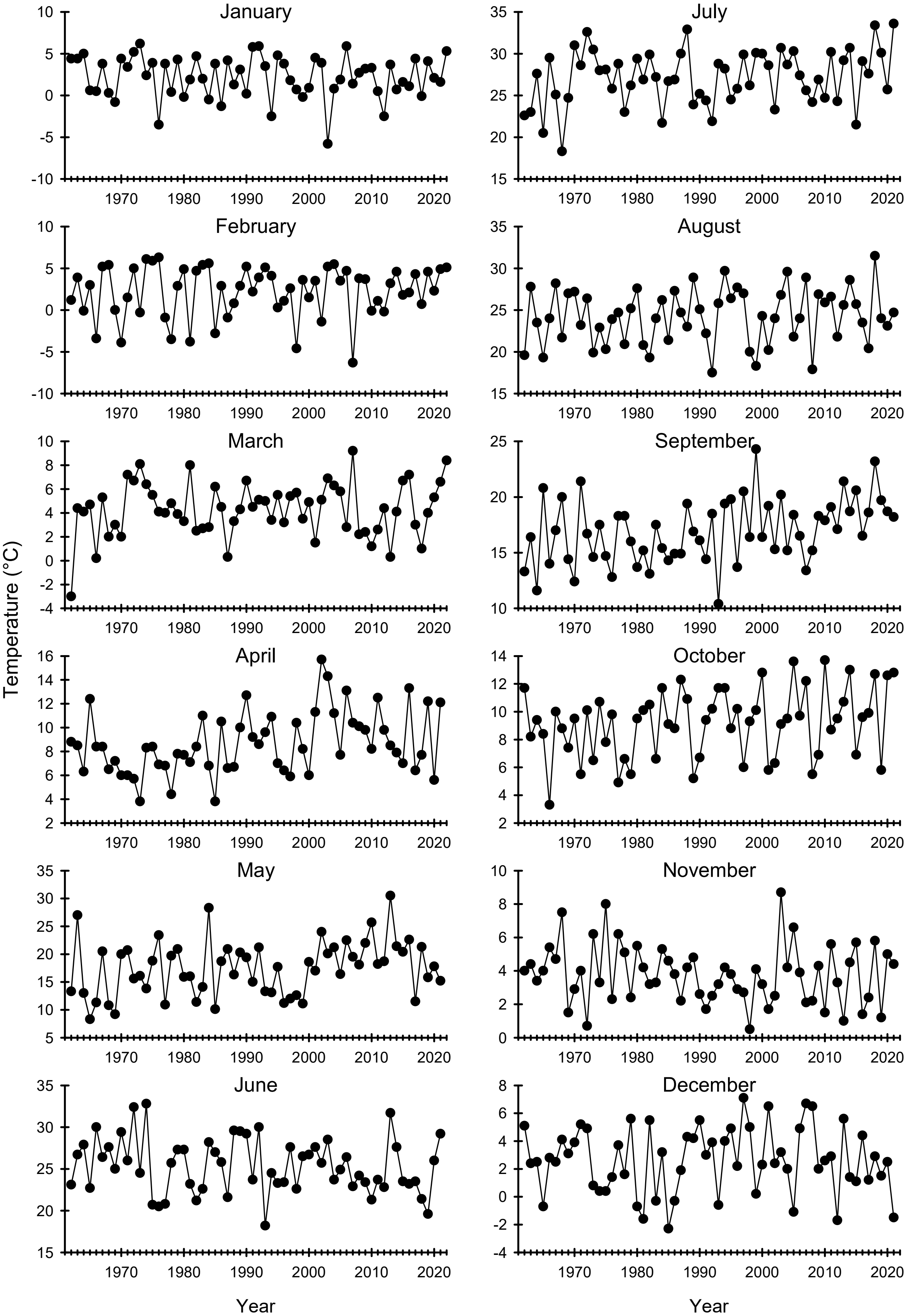


Figure 5. Maximum (highest) daily air temperature values observed in each month at Kevo Station within Tana watershed. Source; Finnish Meteorological Institute.

Figure 5 indicates the highest daily air temperatures in each month during the six decades in the River Tana valley. The highest air temperature values have been observed to take place especially in July, August, September and in October and especially in the latest years. Water levels and discharges are most commonly at its lowest in July. The ascend of small salmon (one sea winter fish) into the northern rivers happens simultaneously. This abnormal low water level together with simultaneous high air temperatures is making water temperatures too warm for salmon and therefore salmon migration into the rivers or migrations within the rivers can be ceased. High water temperatures and simultaneously low water levels has negative effects on the rod fishery. Very low water levels, however, can make fishing with gillnets and weirs very effective in the River Tana watershed.

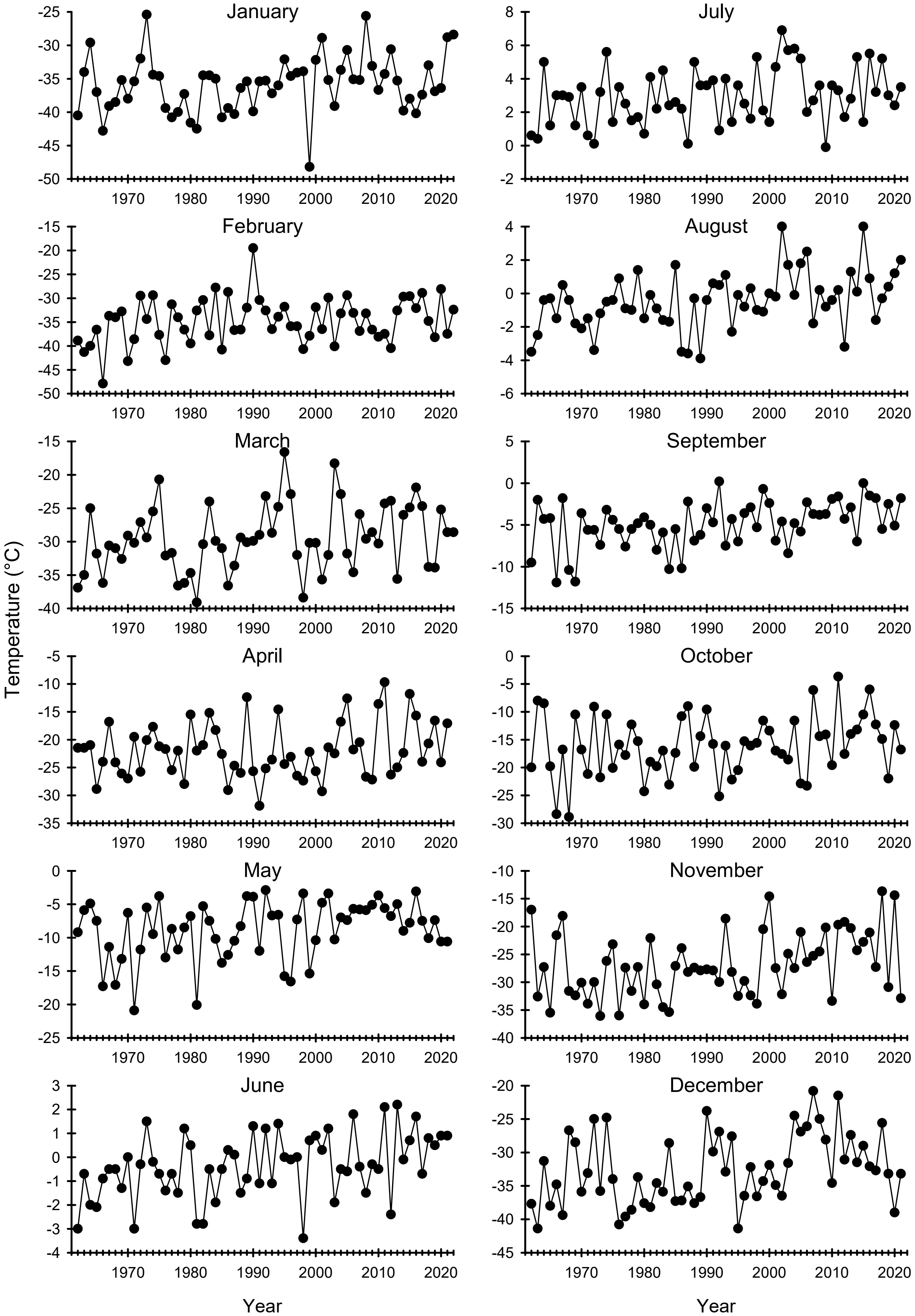


Figure 6. Minimum (lowest) daily air temperature values observed in each month at Kevo Station within Tana watershed. Source; Finnish Meteorological Institute.

In the recent decade the daily minimum air temperatures in each month have not been so low compared to the minimum daily temperatures in 1960's and 1970's (Fig. 6). This can be observed clearly in all months of the year and especially from January to August.

Figures 7 and 8 are also indicating some increase in the last decade in the long-term mean temperatures especially in April, May, August and September.

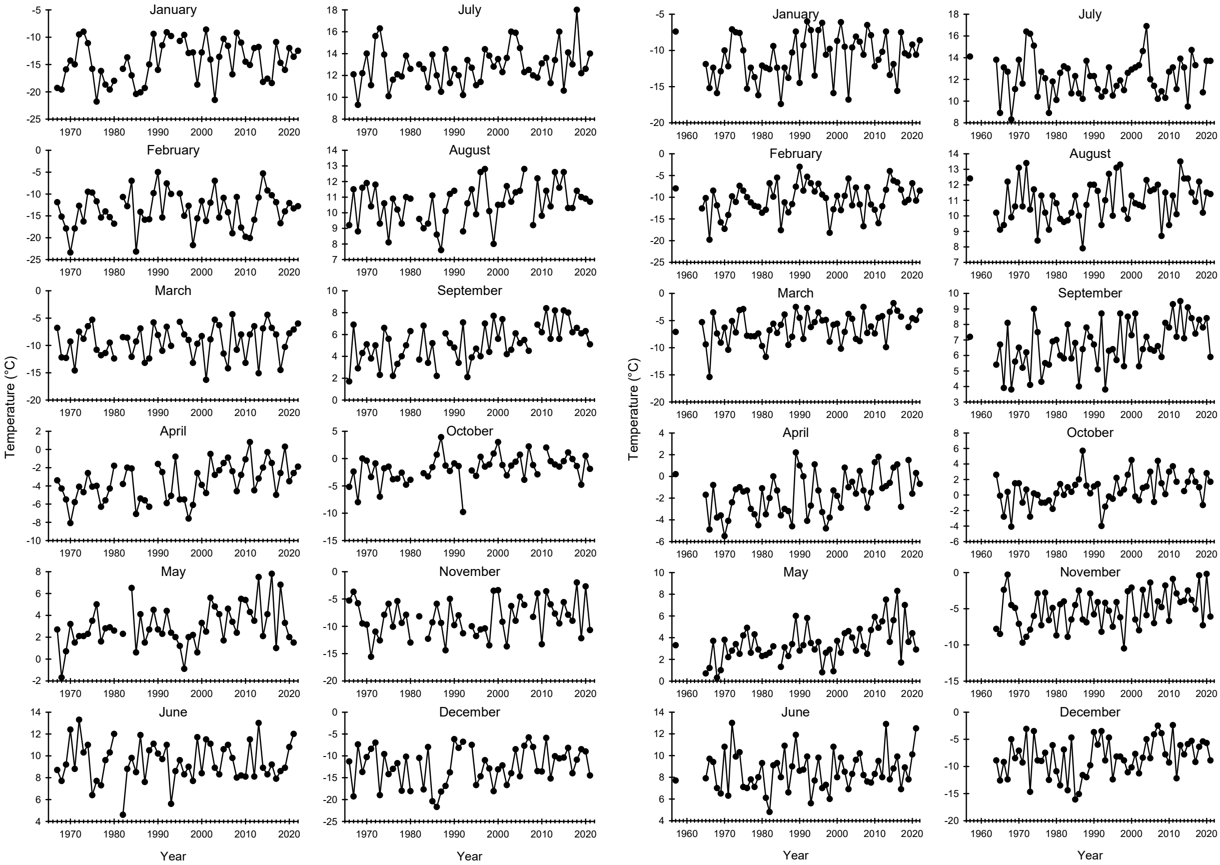


Figure 7. Monthly mean air temperatures at Cuovddatmohkki station in Karasjohka municipality (on the left) in the River Iesjohka and at Kirkenes Lufthavn in Sør-Varanger municipality (on the right). Source; Norsk Klimaservicesenter.

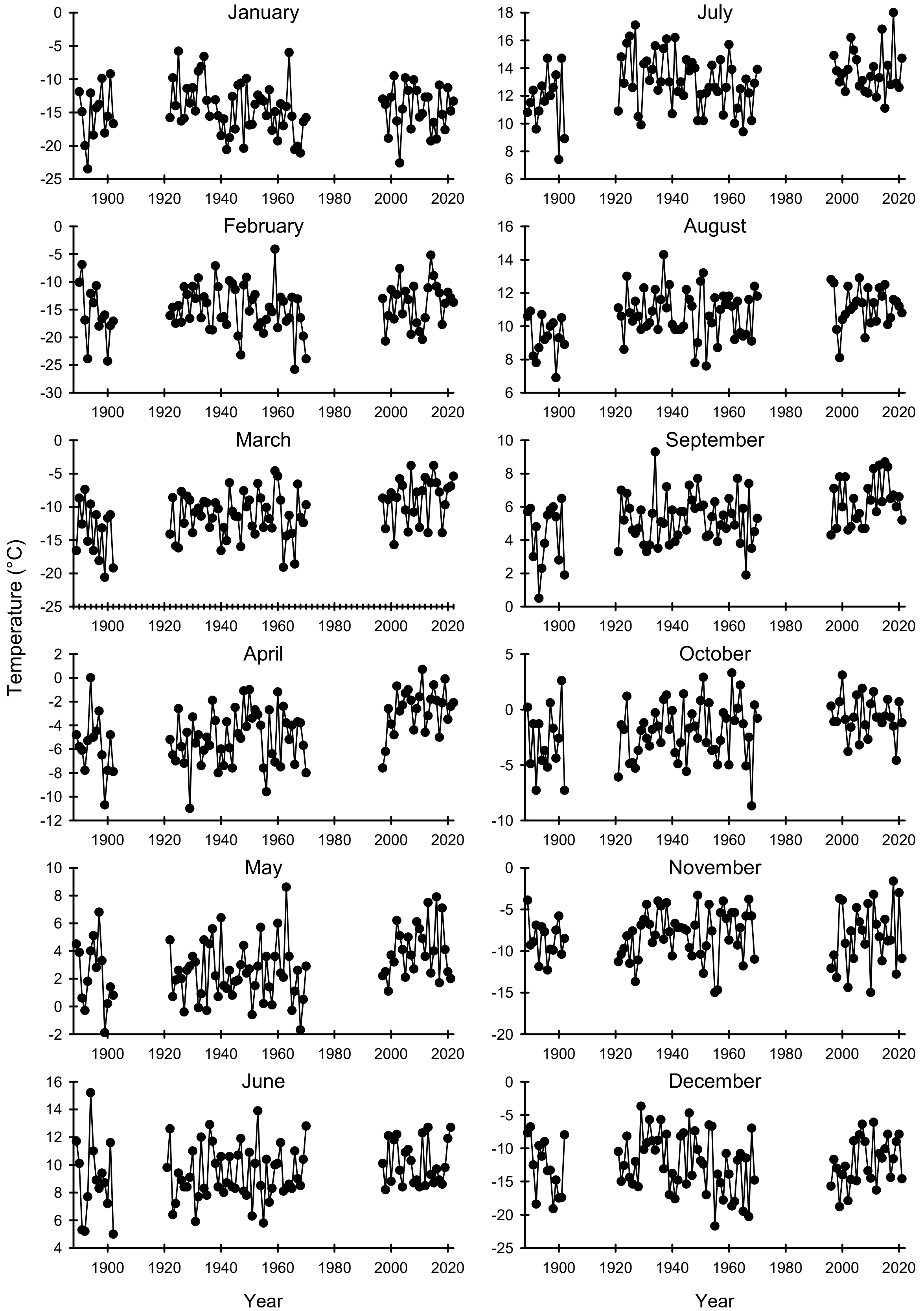


Figure 8. Monthly mean air temperatures at Kautokeino station in Kautokeino municipality. Source; Norsk Klimaservicesenter.

2. Air temperatures are reflecting obviously into the running water temperatures

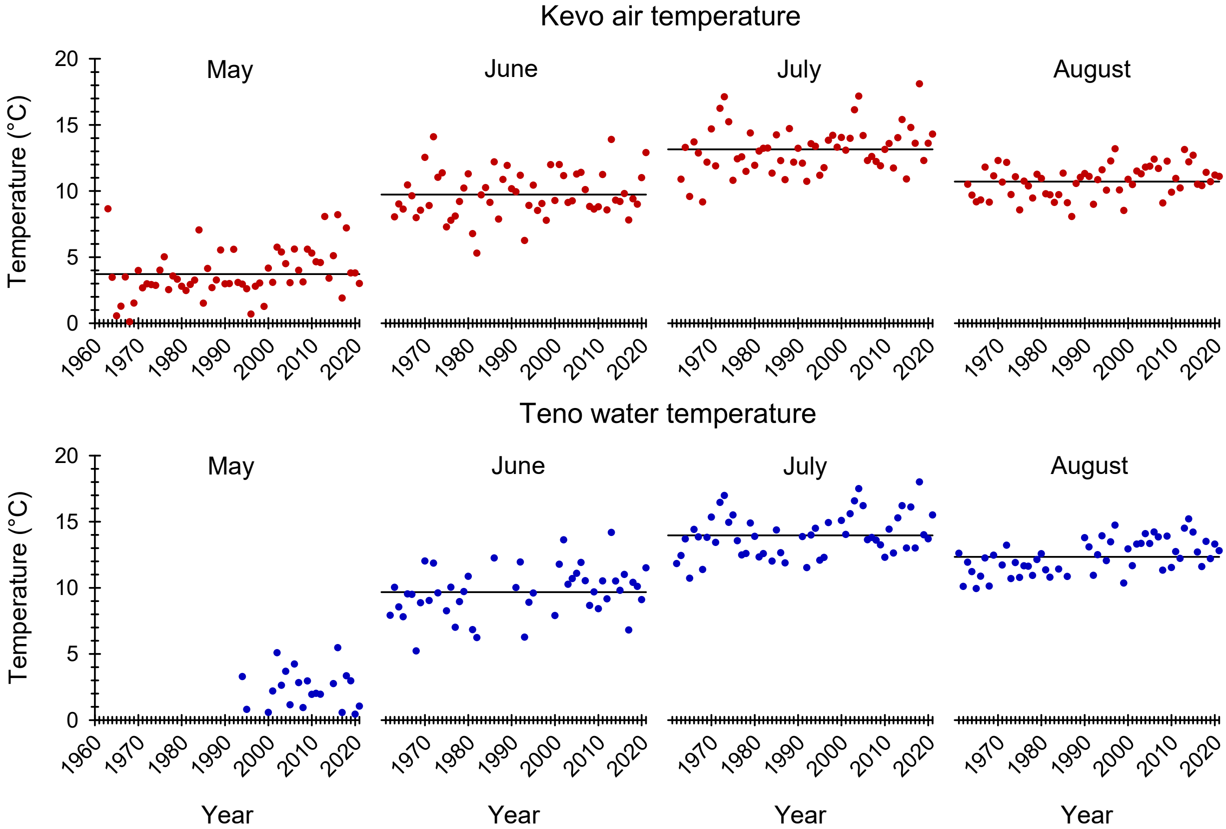


Figure 9. Monthly mean air temperatures at Kevo Station, Utsjoki, and monthly mean water temperatures in the River Tana/Teno. Source; Finnish Meteorological Institute (Finland), NVE (Norway), Finnish Environment Institute (Finland).

Figure 9 indicates large annual variations both in the monthly mean air temperatures at Kevo station, Utsjoki, and in the mean monthly water temperatures in the River Tana. In the early 1970's, there was short warm period in mean air and mean water temperatures that can be observed in July and August. The warm period was followed by a period with colder air and water from the end of 1970's, lasting around 10 years. This can be observed especially in July. Simultaneous increase in the mean air and water temperatures can be observed in August from the late 1970's onwards.

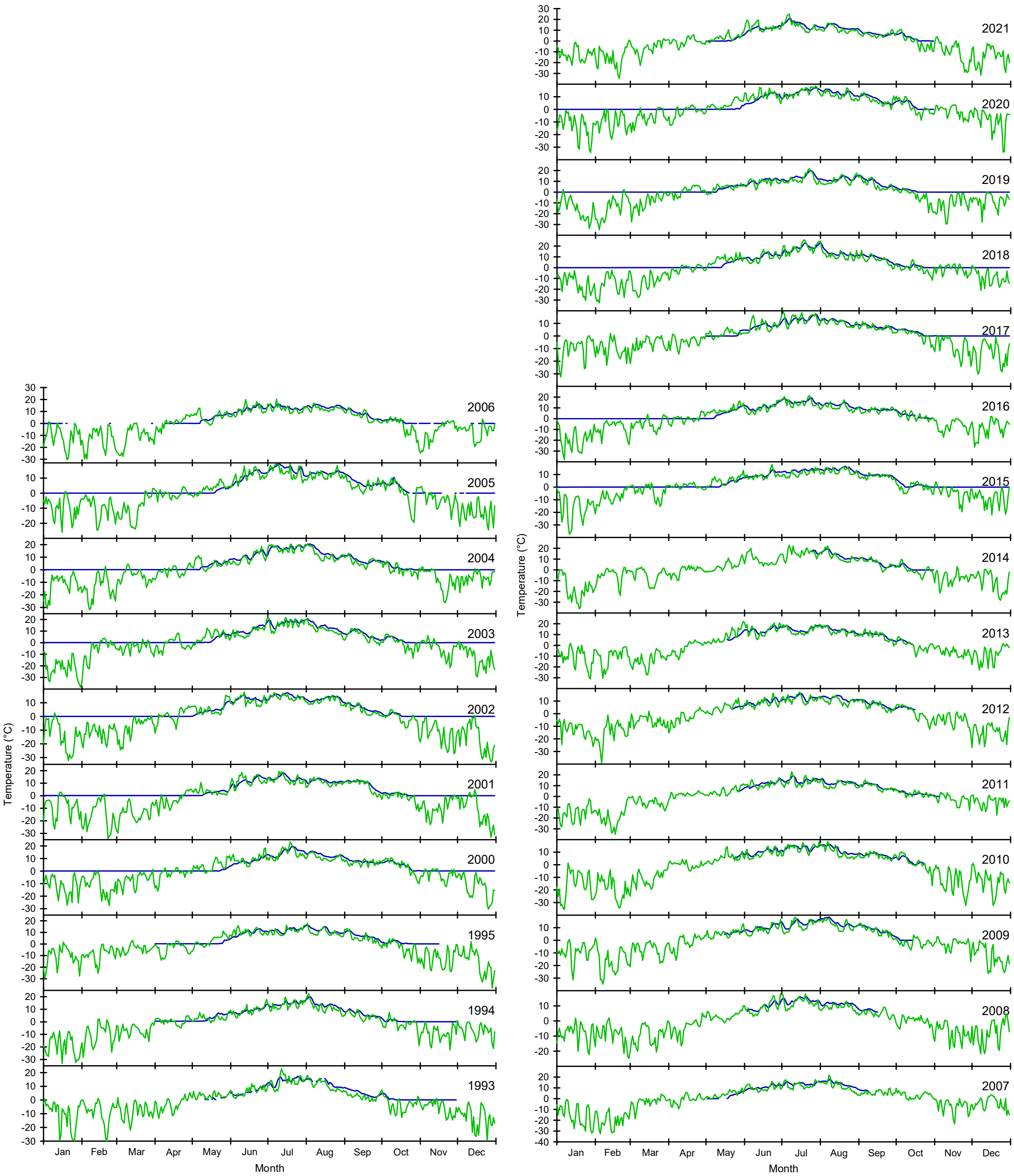


Figure 10. Daily mean air temperatures at Kevo Station, Utsjoki, within Tana/Teno watershed (green curve) and daily mean water temperatures in the River Tana (blue curve) in the years 1993-2021. Source; Finnish Meteorological Institute (Finland), NVE (Norway).

Daily variations in long-term Kevo air and Teno water temperatures are illustrated through three decades (Fig. 10). There is clear simultaneous fluctuation between mean daily air and water temperatures, and especially from late June to late August. River Teno is normally covered with ice from November-December to May the following year, and in this period the water temperatures are around 0°C.

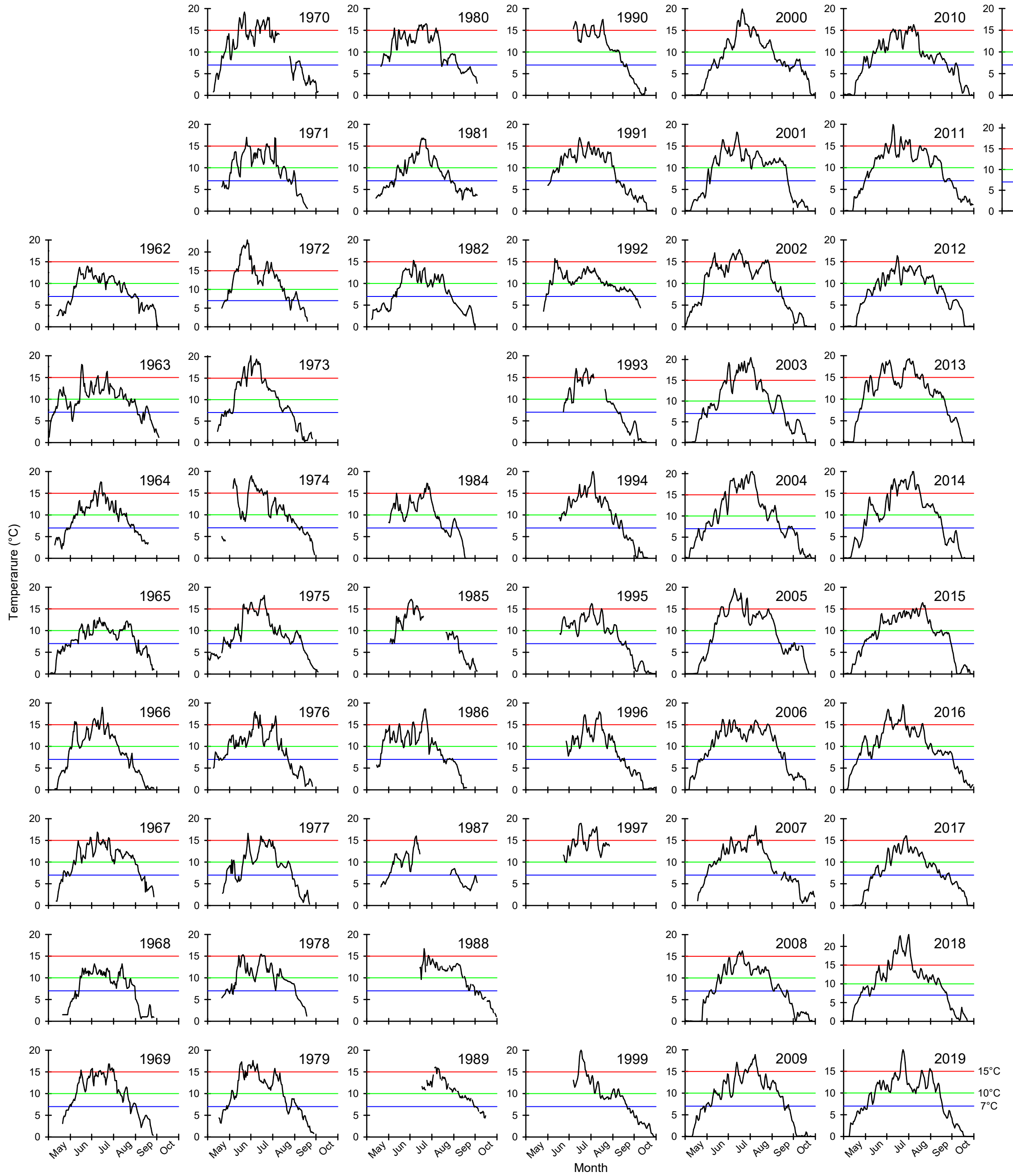


Figure 11. Water temperatures in the River Tana/Teno in the summer period when ice does not cover the river. Measurements in the period 1962-1989 are taken daily at 12:00 o'clock at Teno/Onnela site (Finnish Environment Institute) and in Tana /Polmak site at 12:00 o'clock in the period 1990-2021 (NVE Norway). Blue, green and red lines indicate periods when water temperatures are exceeding 7°C, 10°C,15°C.

Daily water temperatures in the River Tana have exceeded 15°C in recent decades more frequently than in 1960's (Fig.11). The warmest water temperatures up to 25°C have been measured in the River Tana during the last years. Since the year 2000, when water temperatures in October have reached 0°C, it has stayed close to that degree until early or middle May the following year (figure 11).

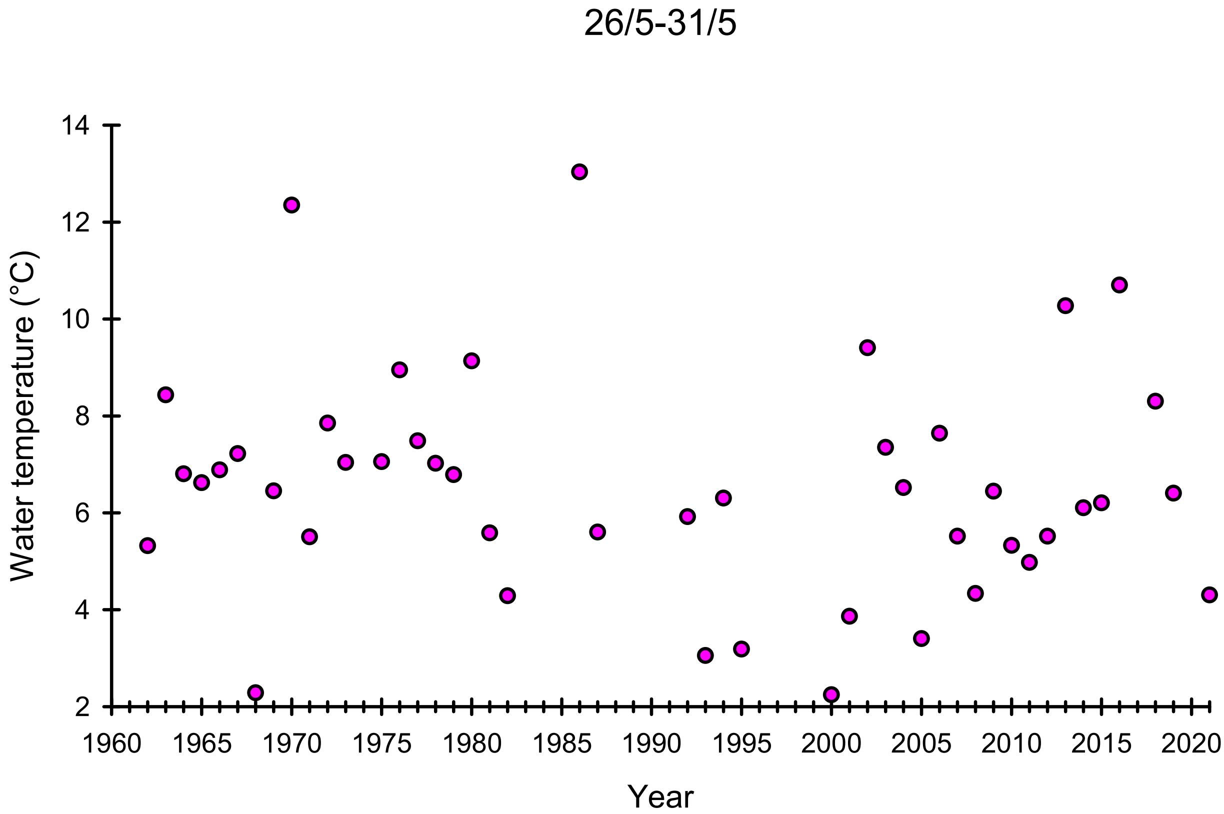


Figure 12. Mean water temperatures in the period of May 26th to31st in the River Tana. Source: NVE (Norway), Finnish Environment Institute (Finland).

In the River Tana ice breaking-up takes place most frequently in the period from early May to May 20th and some few years very late in May. Depending on the ice breaking-up dates, water temperatures increase towards to the end of May. Early ice breaking-up dates results up to 10°C water temperatures in the end of May (Fig.12).

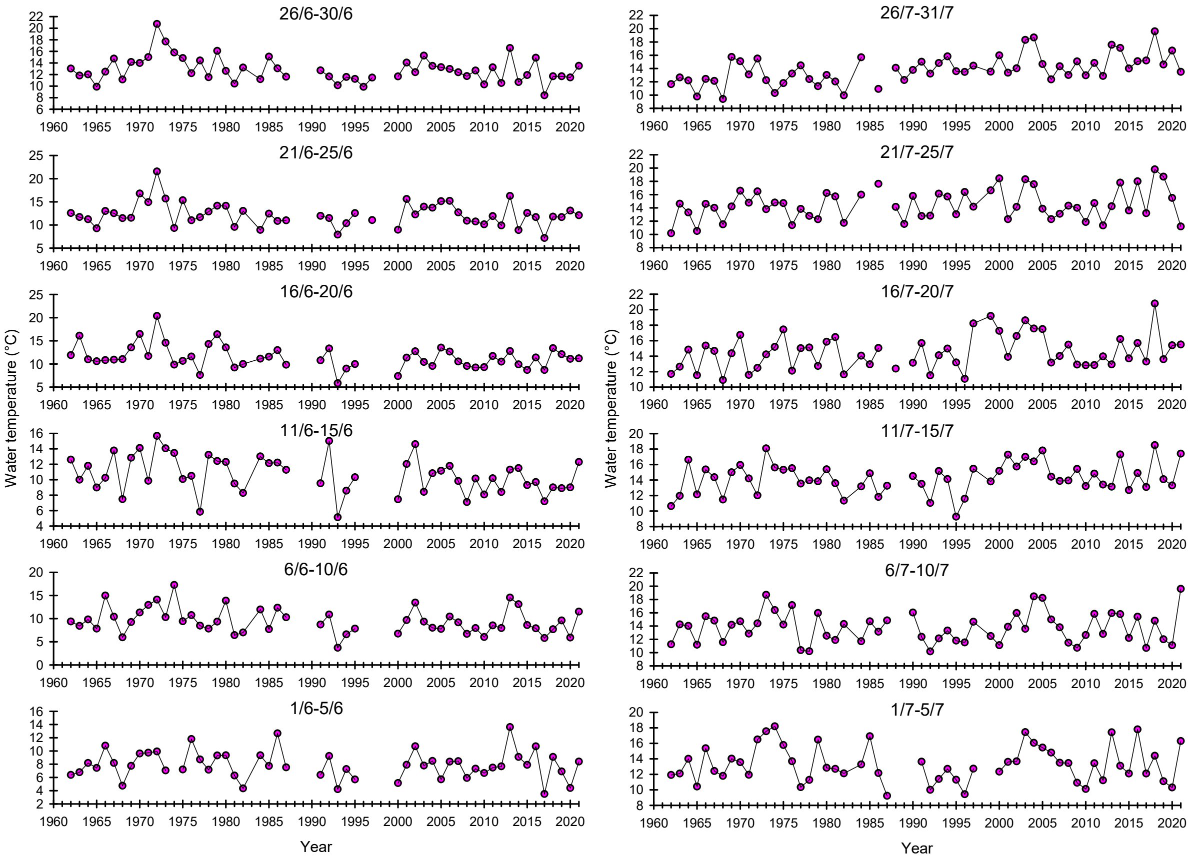


Figure 13. Mean water temperatures in 5 days periods in June and July during 6 decades in the River Tana. Source: NVE (Norway), Finnish Environment Institute (Finland).

In long-term in June there cannot be observed clear trends in the mean temperatures for those 5 days periods (Fig.13). From the middle of July, however, there has been more or less a clear increase along the years in the 5 days water temperatures with noticeable annual variations.

Throughout all the 5 days periods in August and in September the mean water temperatures in the River Tana increased in long-term from early 1960's to 2010's (Fig.14). Also in August and September there was noticeable annual variations.

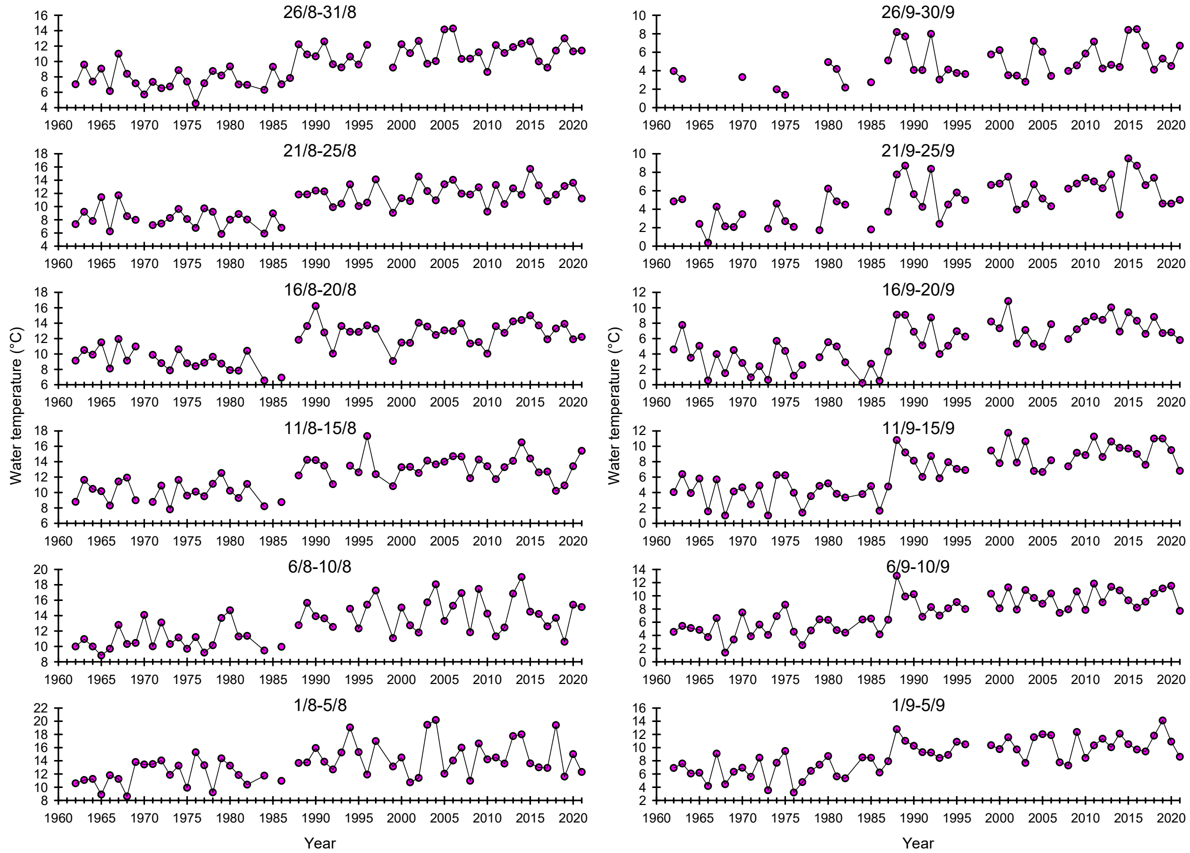


Figure 14. Mean water temperatures in 5 days periods in August and September during 6 decades in the River Tana. Source: NVE (Norway), Finnish Environment Institute (Finland).

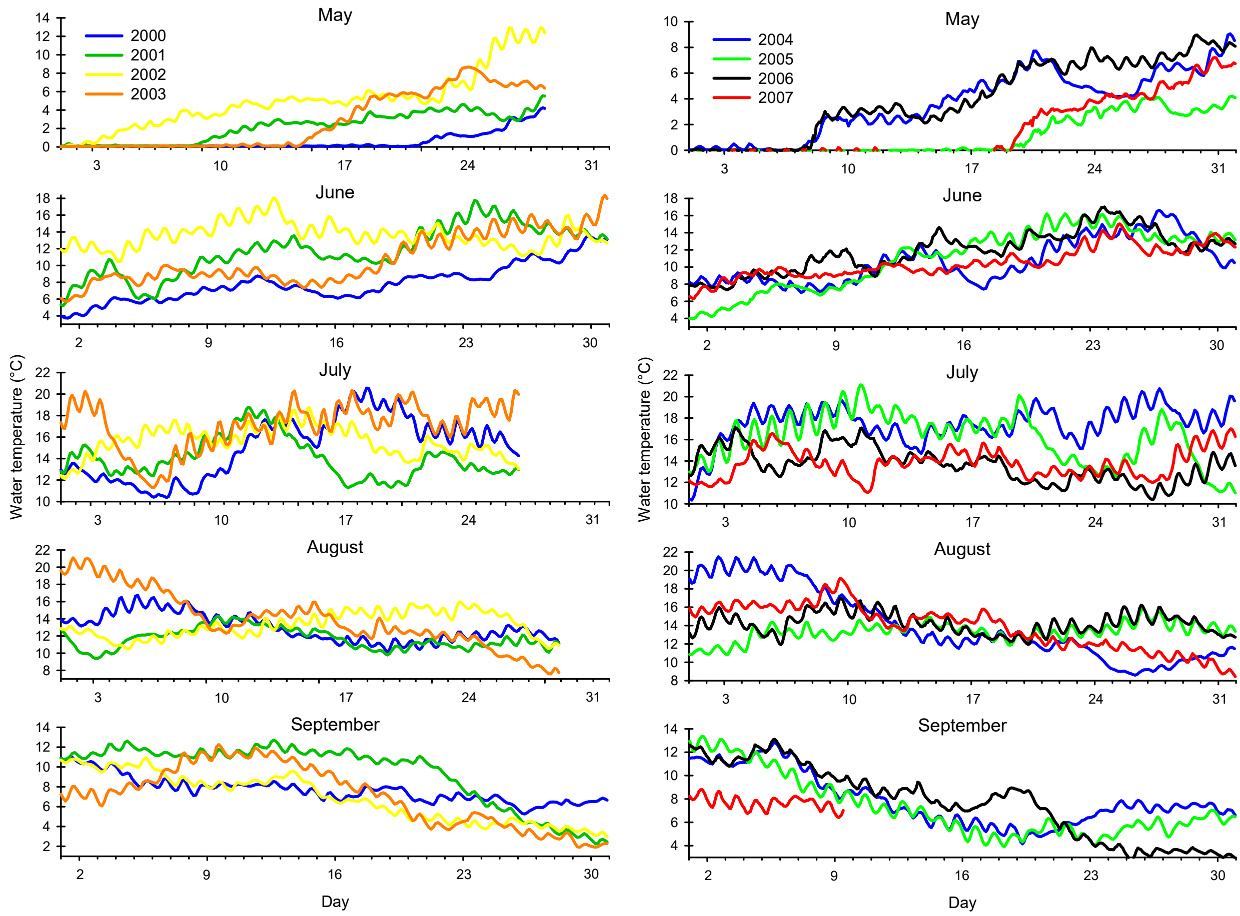


Figure 15. Diurnal water temperature variations in the River Tana/Teno are following the changes in the air temperatures, especially in June, July and August in 2000-2007. Water temperatures are clearly different between the years in the River Tana/Teno mainstem. Source; NVE (Norway).

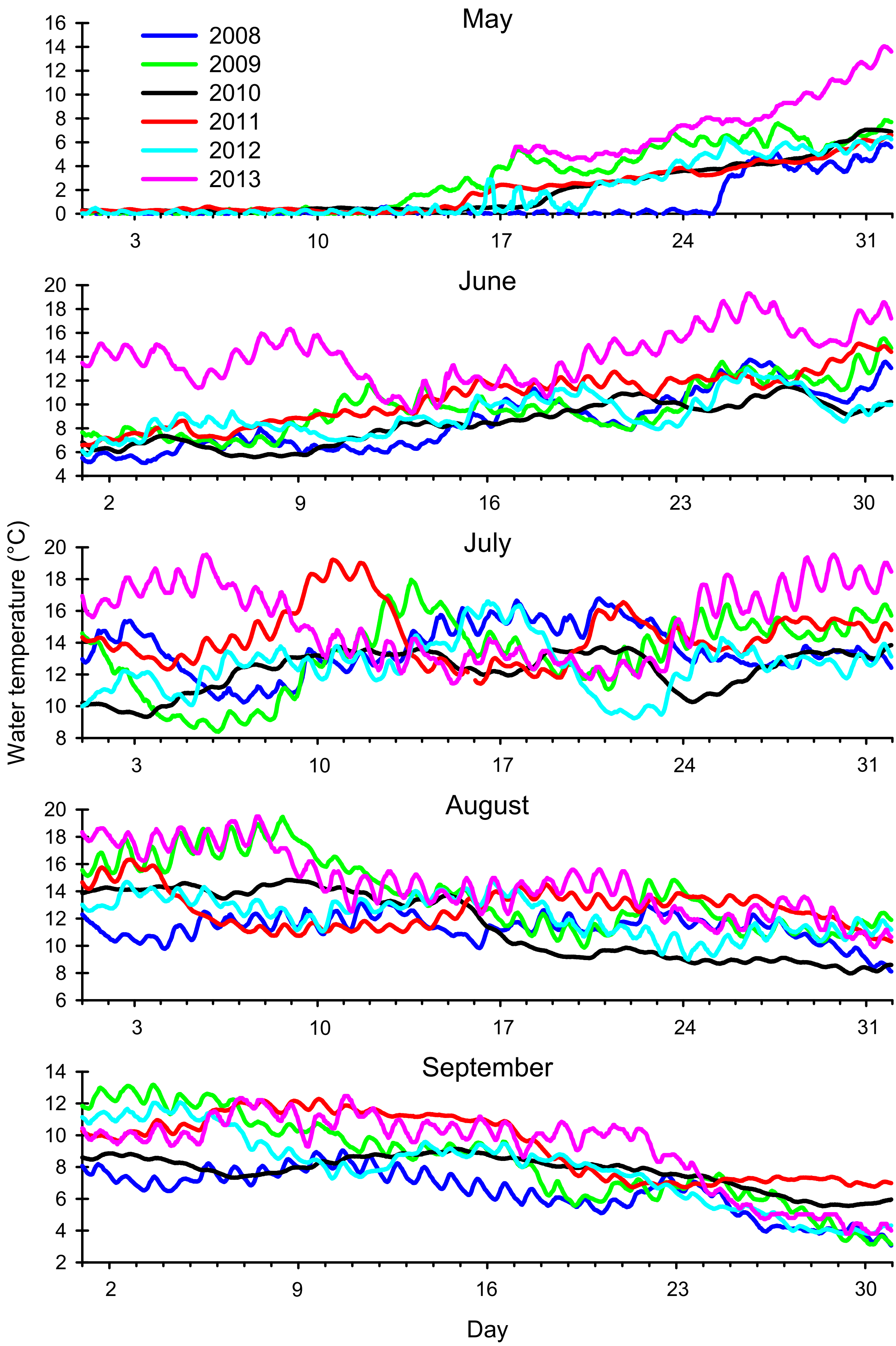


Figure 16. Diurnal water temperature variations are following the changes in the air temperatures especially in June, July and August in the years 2008-2013. Water temperatures are clearly different between the years in the River Tana/Teno mainstem. Source; NVE (Norway).

Figures 15 and 16 are indicating wavelike fluctuations in the diurnal water temperature variations. This reflects the air temperature regular diurnal variation between day and night. Although sun is shining throughout the entire night, its effect to warm air and running waters is weaker during the day. The most important factor to why river temperatures have huge diurnal variations which follows air temperature diurnal variations, is that within Tana watershed there are very few lakes that could equalize temperatures in rivers and brooks. Most of the tributaries and all brooks are running into the River Tana mainstream steeply from the mountains and therefore running waters in riffles, rapids and waterfalls are in contact to the air temperature variations.

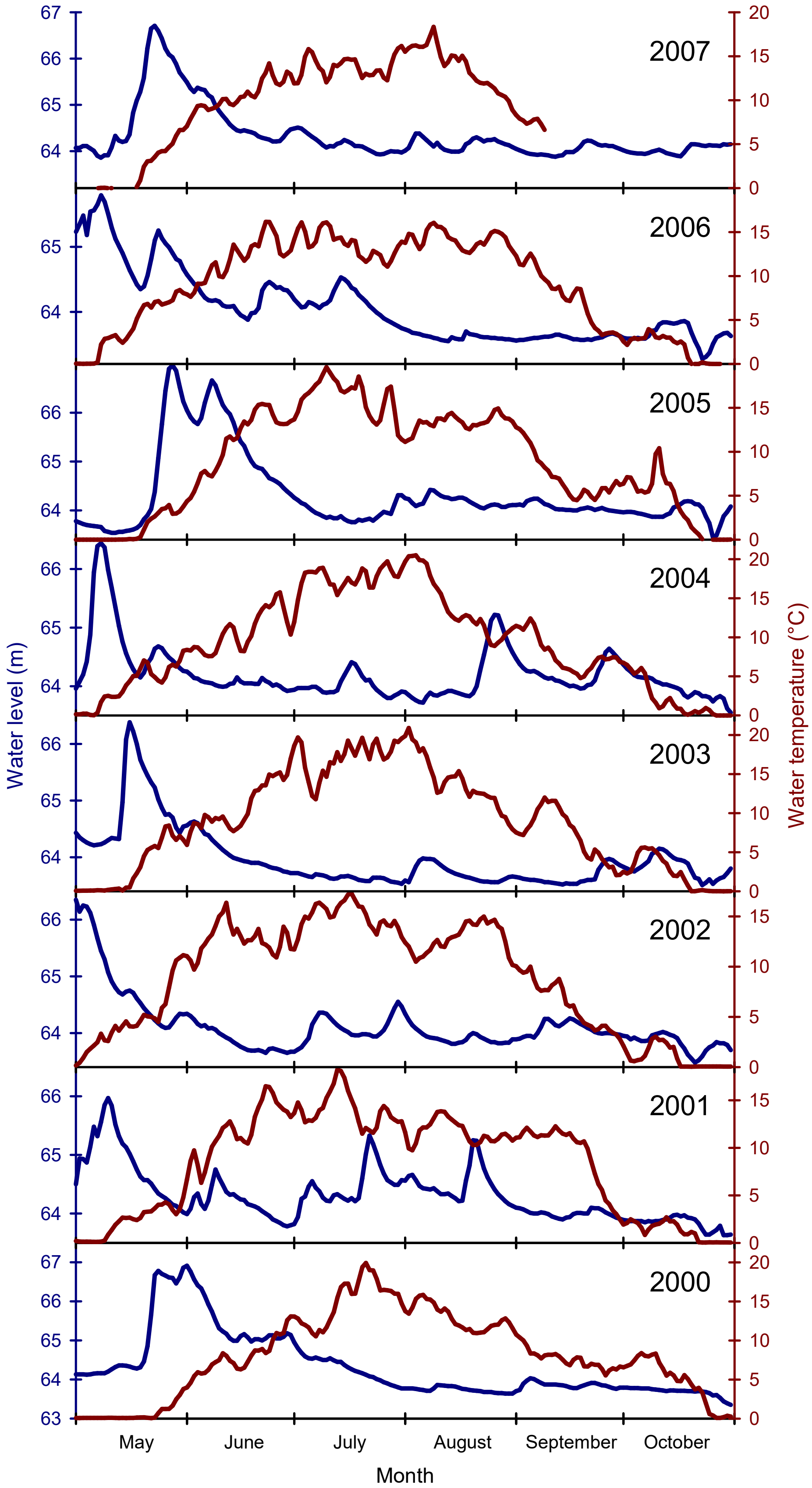


Figure 17. Mean daily water temperatures (brown line) are declining in the River Tana/Teno following a decline in the air temperatures. However, water temperatures are developing opposite to the variations in water levels especially in June, July and August (blue line). Source; NVE (Norway), Finnish Environment Institute (Finland).

It is natural that cooling in air temperatures in summer months usually brings increased precipitation. This sudden precipitation increases water levels in tributary rivers and brooks. Later, when water levels declines, the water temperatures are naturally increasing (Fig. 17).

Figures 18-20 presents close relations between local mean daily air temperature variations and daily mean river temperatures. Daily mean temperatures in rivers follows air temperatures variations in all summer months from June to September in the River Tana/Teno watershed. The distance of the rivers from Kevo Meteorological Institute does not seem to be relevant. In some rivers situating far away from Kevo, like in the rivers Levajohka and Kuoppilasjohka, the river and air temperature fluctuations are following each other although water temperatures are quite low.

Daily mean water fluctuations in the river Tana are not so clear compared to temperatures in tributaries. The reason is the fact that there is high discharge in the Tana mainstem which doesn't respond so fast into the daily changes in air temperature variations.

Mean daily water temperatures early in the summer, especially in the River Levajohka but also in the River Kuoppilasjoki, are clearly lower compared to air temperatures. The reason that melting snow in the upper parts of the rivers reaches these tributaries and keeps running waters in these rivers very cold until late June and sometimes until early July.

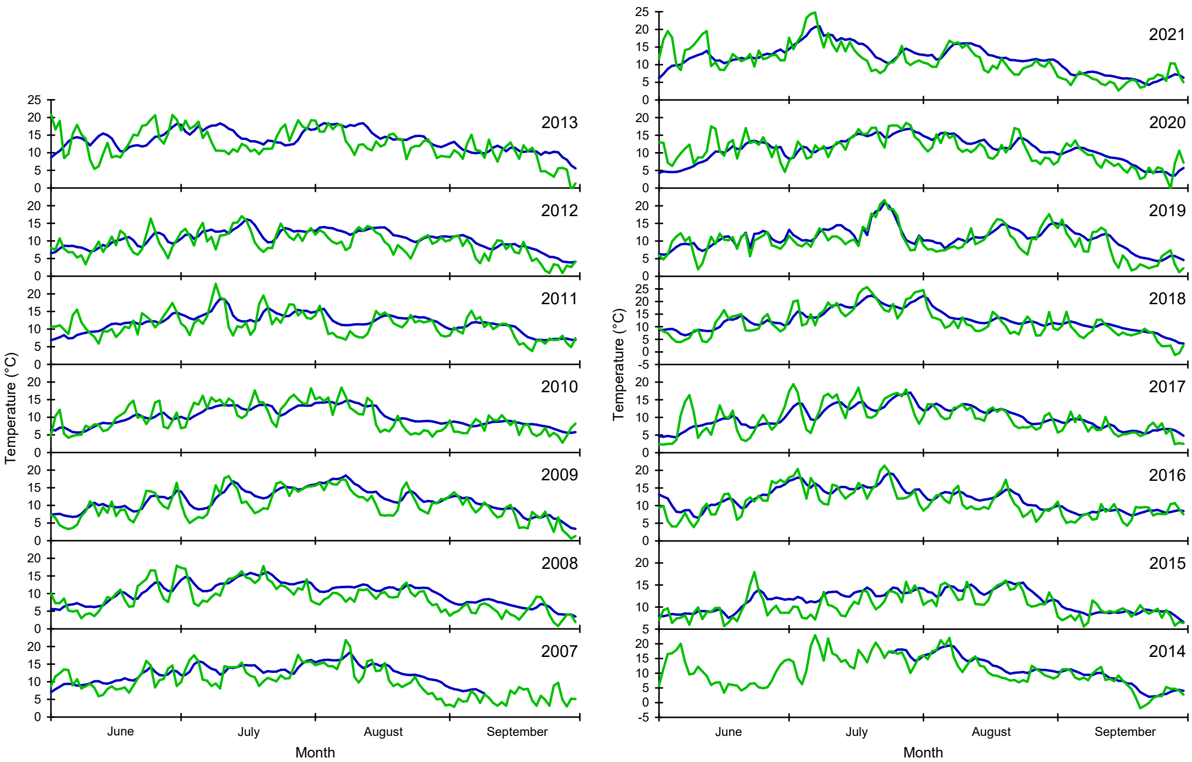


Figure 18. Daily mean air temperatures at Kevo Station, Utsjoki, (green curve) and daily mean water temperatures (blue curve) in summer in the River Tana in the years 2007-2021. Source; Finnish Meteorological Institute, NVE Norway.

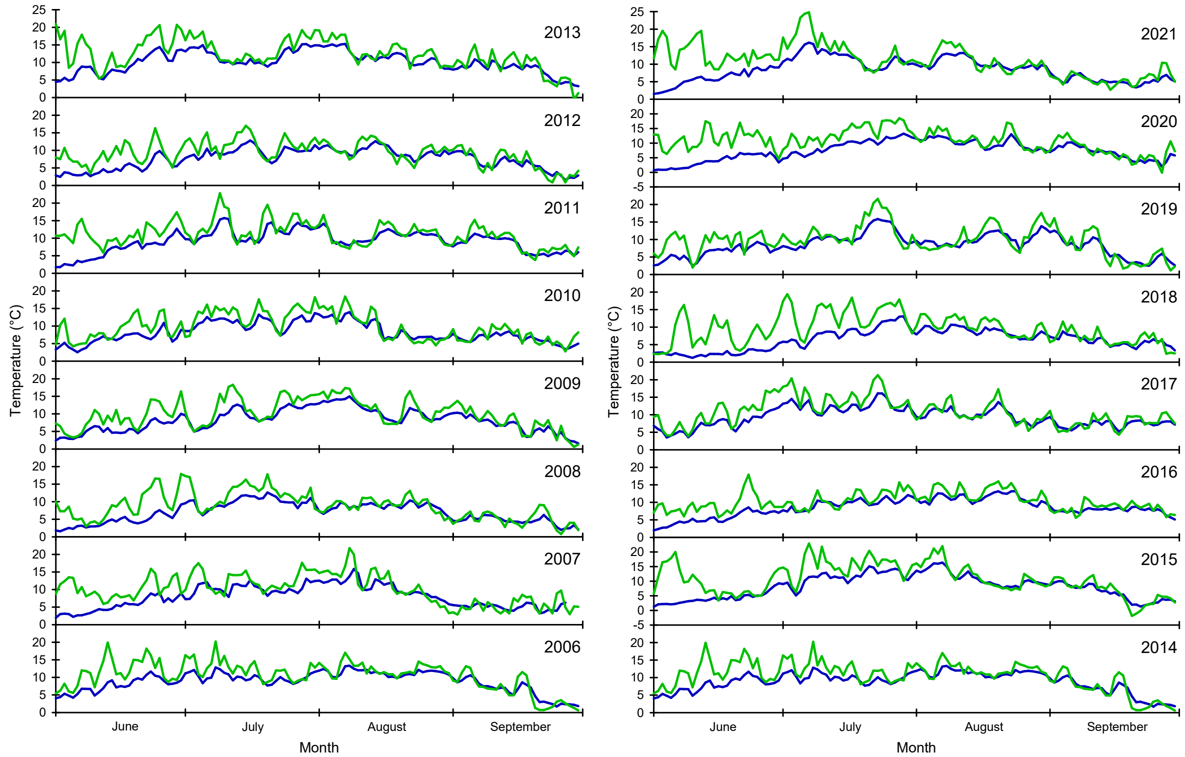


Figure 19. Daily mean air temperatures at Kevo Station, Utsjoki, (green curve) and daily mean water temperatures (blue curve) in summer in the River Levajohka in the years 2006-2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

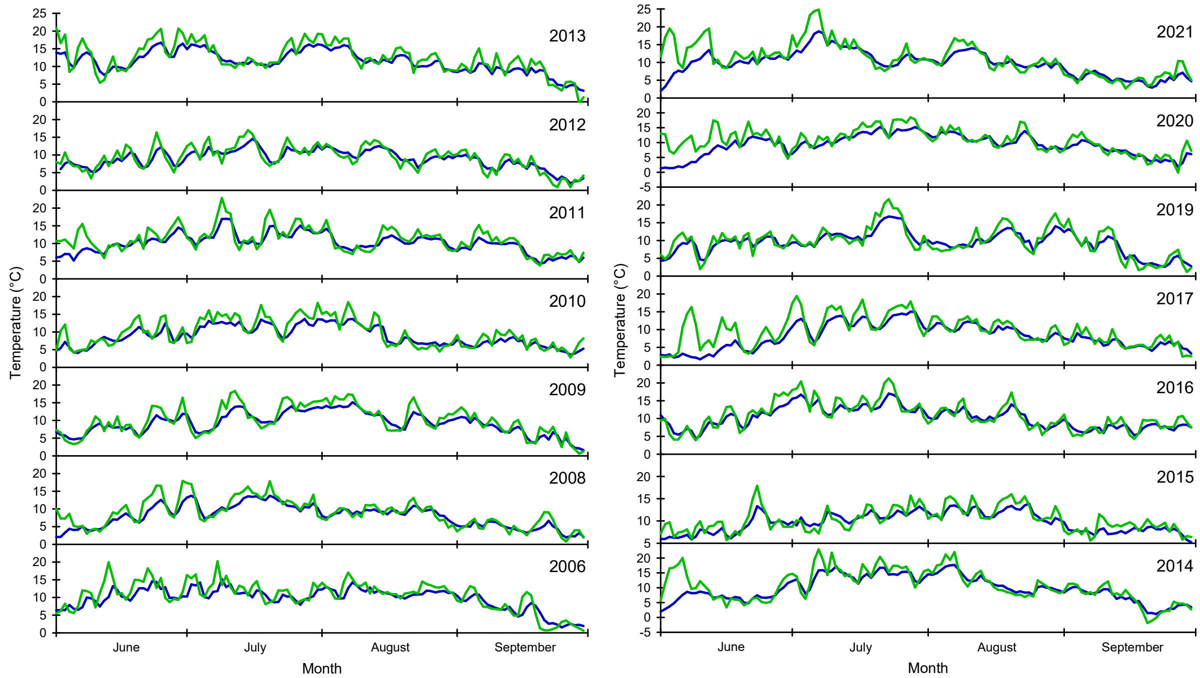


Figure 20. Daily mean air temperatures at Kevo Station, Utsjoki, (green curve) and daily mean water temperatures (blue curve) in summer in the River Kuoppilasjoki in the years 2006-2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

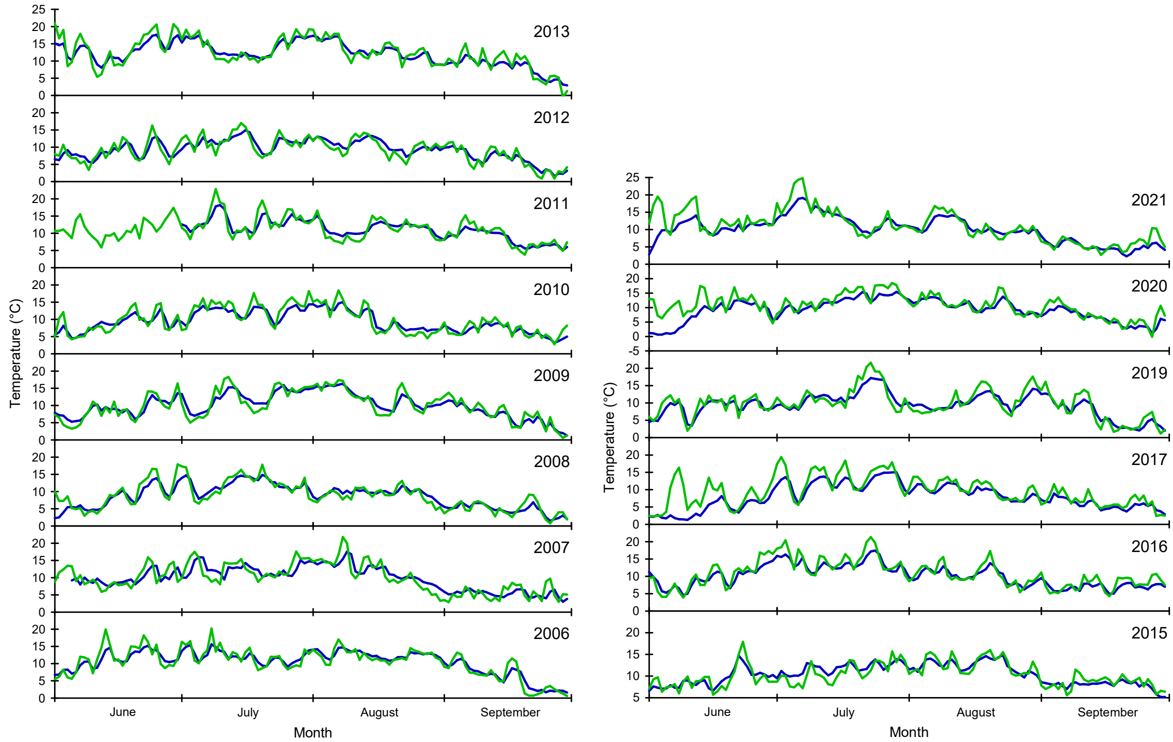


Figure 21. Daily mean air temperatures at Kevo Station, Utsjoki, (green curve) and daily mean water temperatures (blue curve) in summer in the River Tsarsejoki in the years 2006-2021.

Tsarsejoki locates within the distance of 2 kilometers from Kevo Station and therefore temperatures follows each other closely (Fig. 21). Source; Finnish Meteorological Institute, Luke (Utsjoki).

3. Diurnal temperature synchrony between temperature in air, in large rivers and in small brooks in the River Tana watershed

Water temperatures generally follows air temperature fluctuations in small brooks and in large tributaries each hour throughout the entire day. That synchrony is observed especially from June to the end of September when the melting snow in the mountains does not affect water temperatures, except in the River Levajohka where melting snow keeps water temperature low to the beginning of July. In the figures 22 to 32 it is possible to observe nice synchrony between air temperature fluctuations throughout the day and simultaneous water temperature fluctuations. There are some exceptions within this clear synchrony. Hourly water temperatures in the River Tana and in the River Neiden doesn't fluctuate as clearly as in most of the tributaries and brooks. These rivers have such high discharges which do not respond rapidly to the air temperature fluctuations. We can say that temperature circumstances in those large rivers are quite stable, however, temperatures can still rise up to 25°C. Water temperature in the River Tana is a mixture of water temperatures from hundreds of brooks and from many tributaries.

Clearly, River Tana water temperatures in the summer increases if air temperatures are rising. For example, in the year 2018 air temperature in Kevo station reached 32 °C and affected the River Tana water to increase to close to 25°C. These kind of surprising increases in water temperatures might cause disease outbreaks, cessations in salmon migrations towards their spawning grounds, and salmon might migrate back to seawater or to deep pools where they can be overexploited in gillnet fisheries. When the water is too warm, salmon does not bite lures, flies etc. and therefore rod fishery is fruitless. In too warm water, juvenile salmon lose their territorial behavior, their appetite and ceases its feeding. They start to move in schools and are moving from riffles to slow flowing pools. When they move from their ordinary territorial site to secondary habitats, they are more exposed to predation.

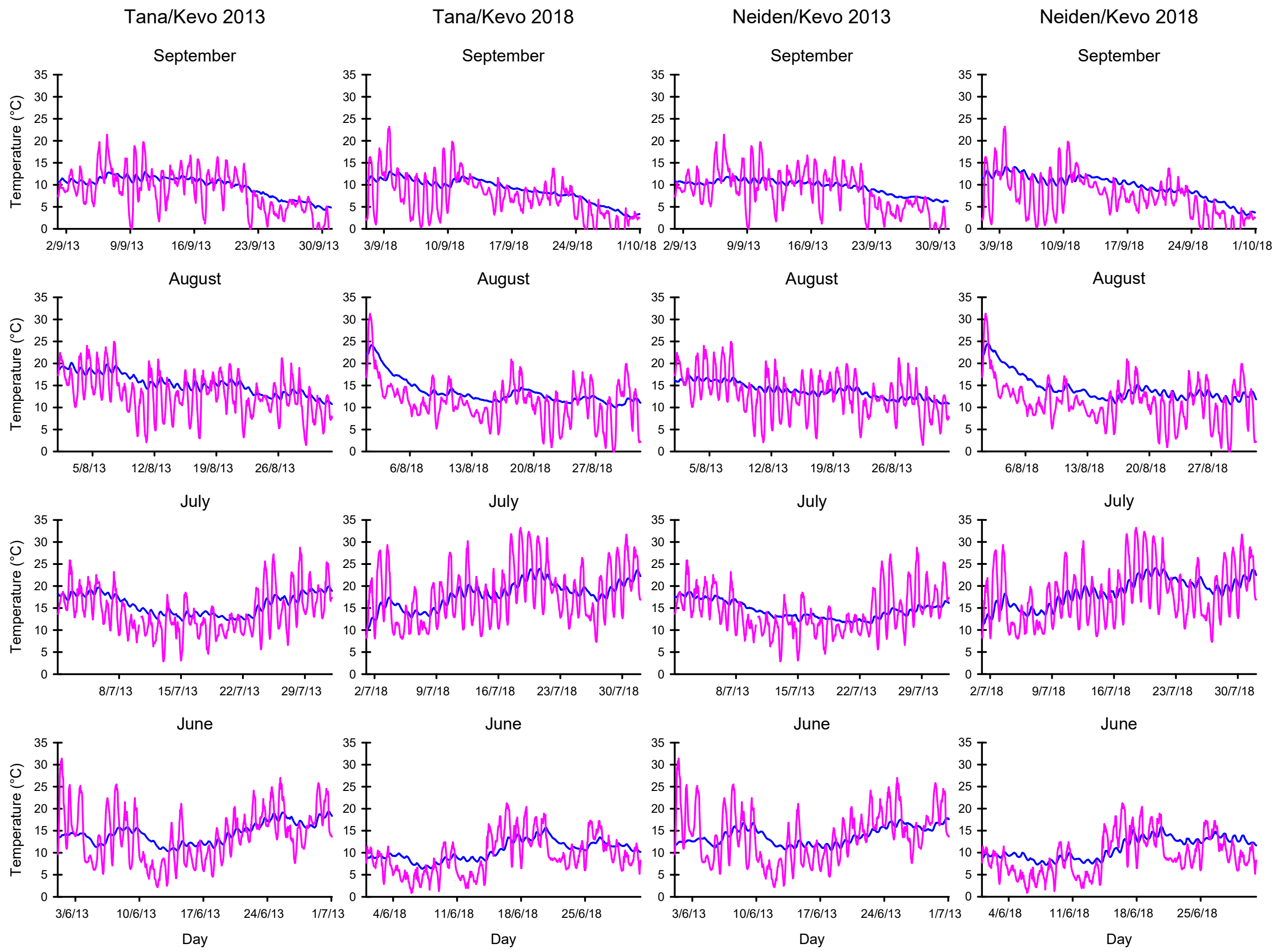


Figure 22. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Tana (figures on the left) and in the River Neiden (figures on the right) in the years 2013 and 2018. Source; Finnish Meteorological Institute, NVE (Norway).

In River Tana's large tributary rivers, the water temperatures are usually following the hourly air temperature variations in the period from June to August.

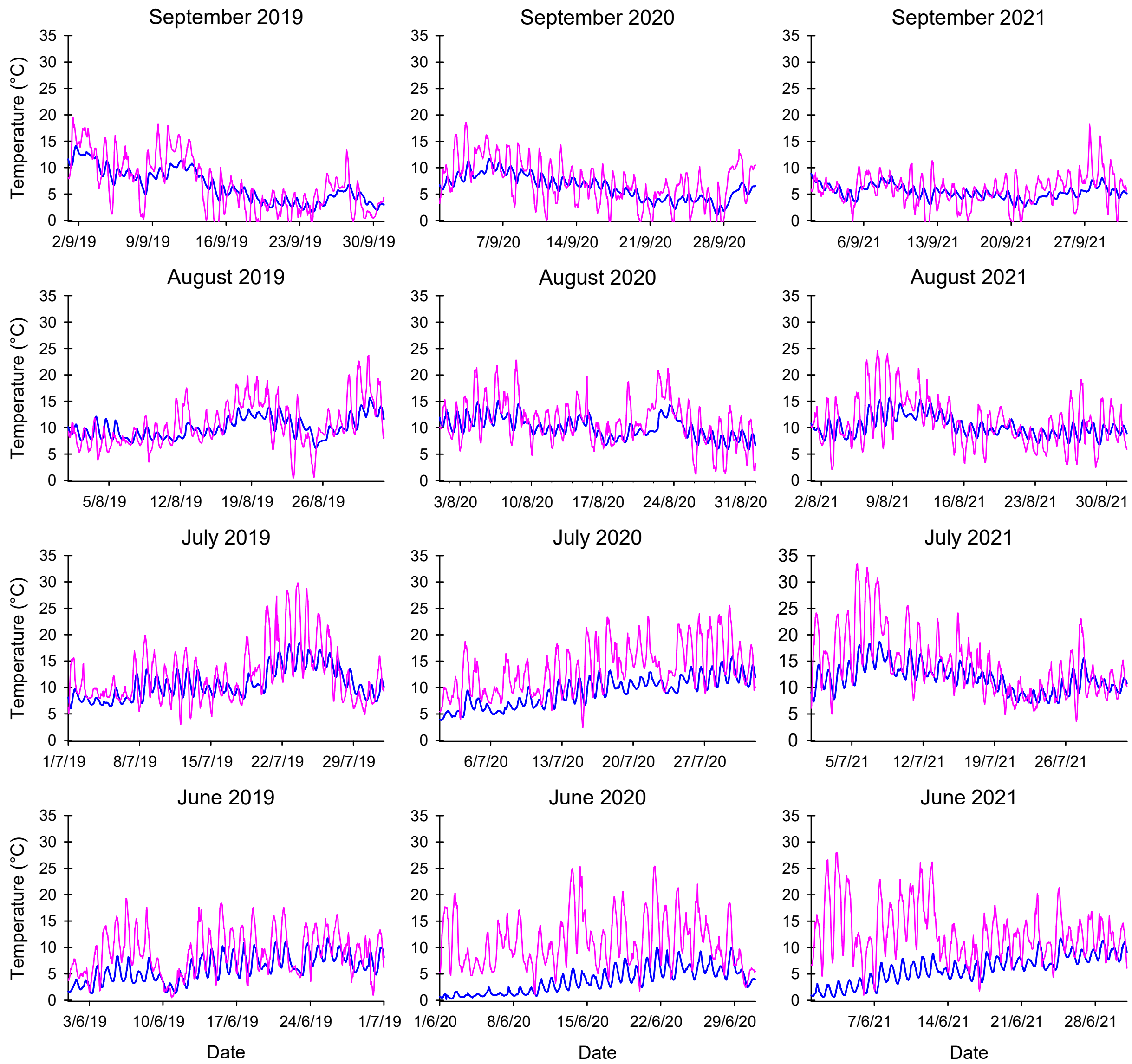


Figure 23. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Levajohka (tributary in Tana) the years 2019, 2020 and 2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

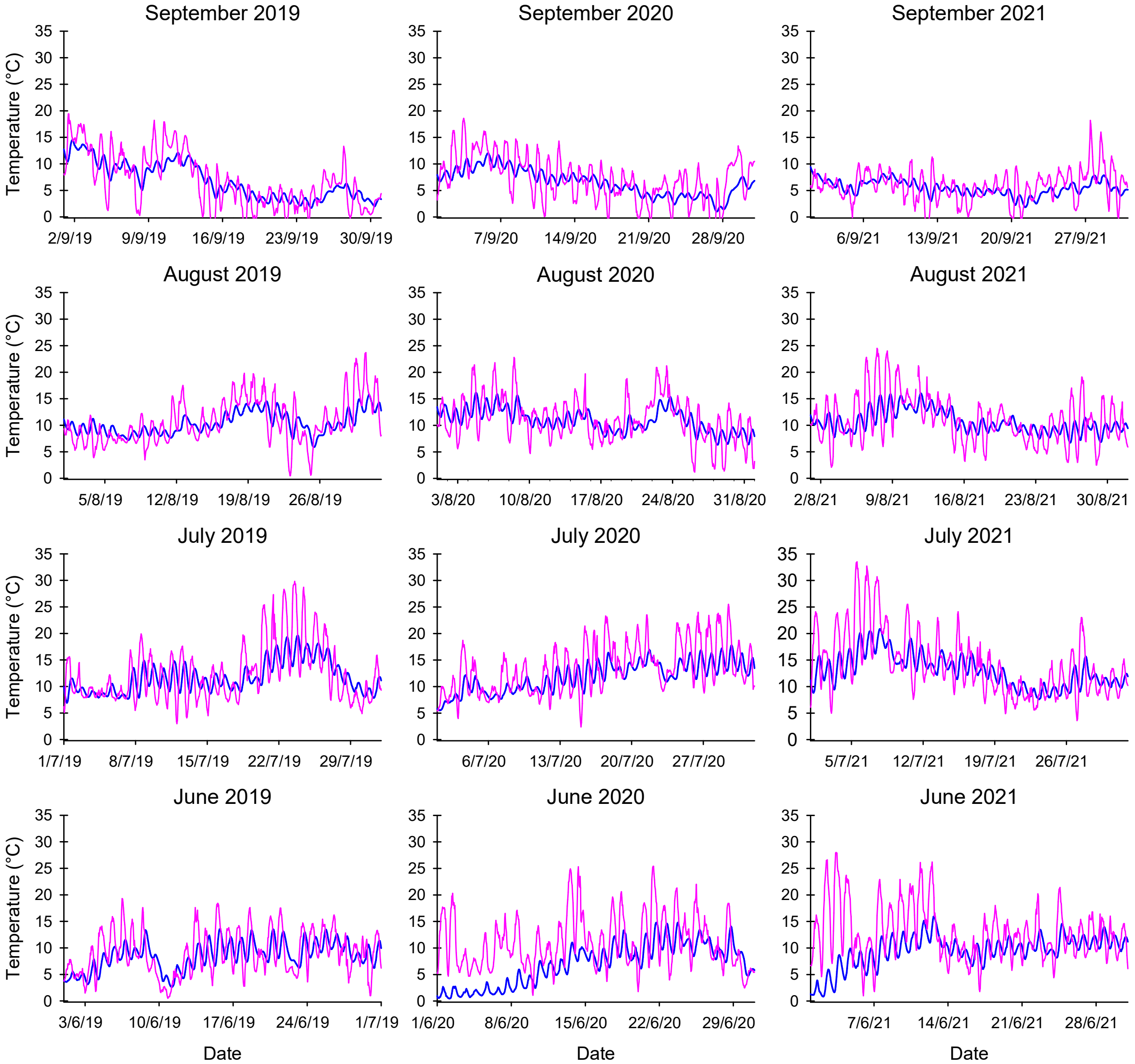


Figure 24. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Kuoppilasjoki (tributary river in Tana) the years 2019, 2020 and 2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

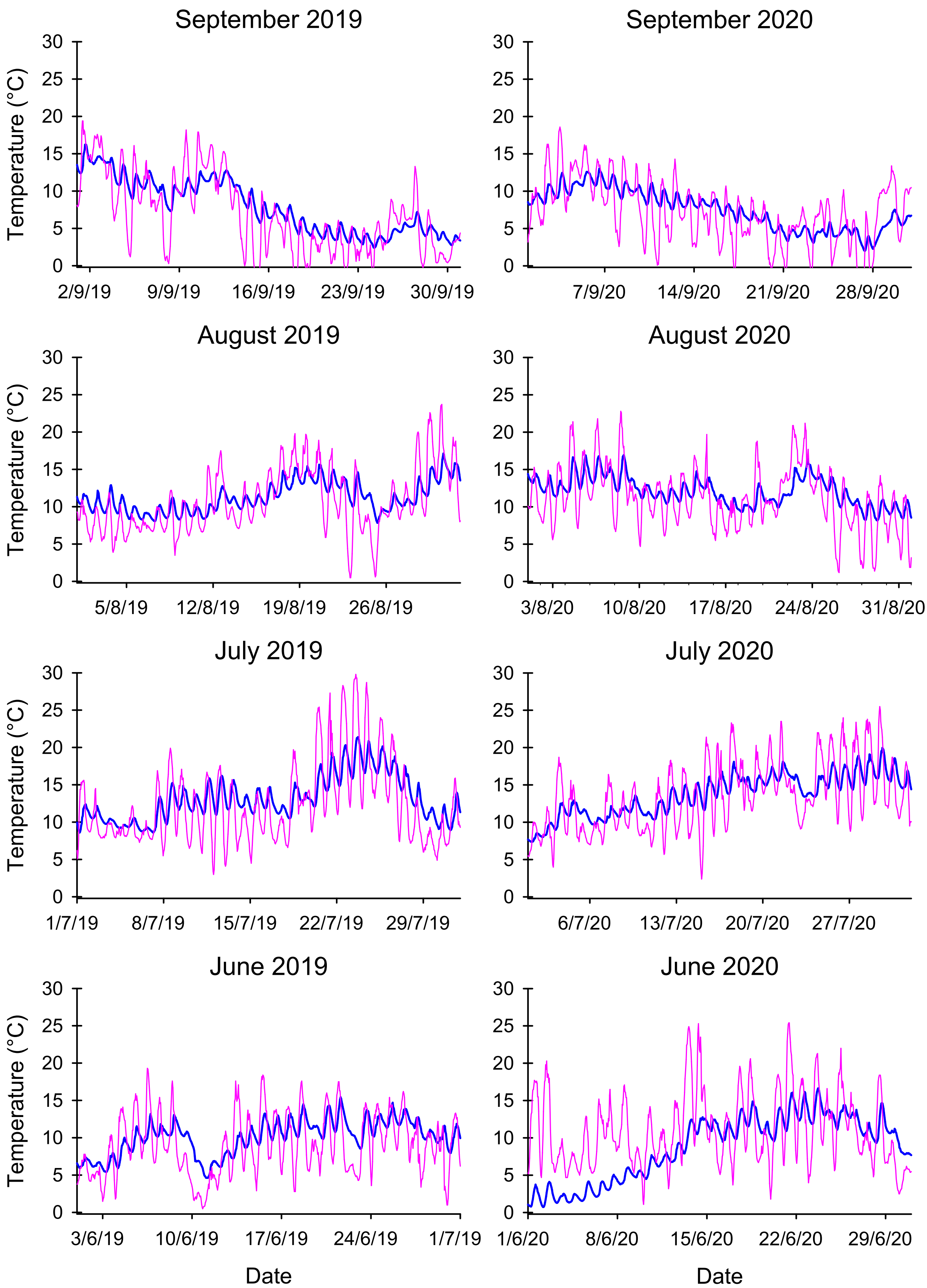


Figure 25. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Vetsikkojoki (tributary river in Tana) the years 2019 and 2020. Source; Finnish Meteorological Institute, Luke (Utsjoki).

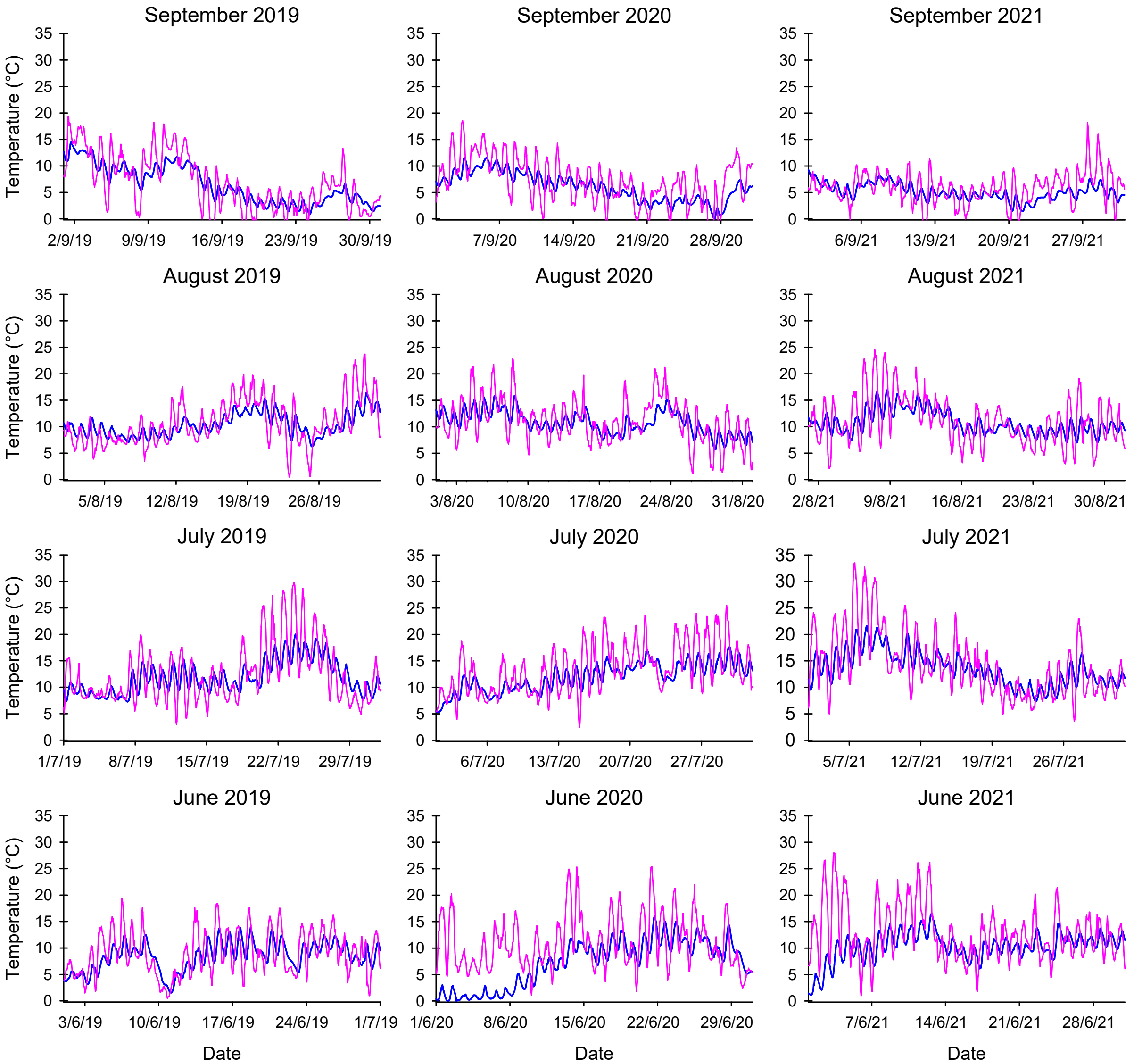


Figure 26. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Tsarsejoki (tributary river in Tana) the years 2019, 2020 and 2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

The river Tsarsejoki is very close to the Kevo Meteorological station (c. 2 km) and here we can observe clear synchrony in the hourly temperature variations between air and water temperatures. Air temperatures in early in July in 2021 were 32-33°C and at the same time water temperatures rose up to 22°C. If air temperatures in July for a longer period stay above 30°C, the water temperatures can increase up to 25°C in the tributaries of Tana. The reason is that the discharges are lowest in July and August, allowing for the temperature to increase. Those kinds of environmental factors might be lethal for adult salmon.

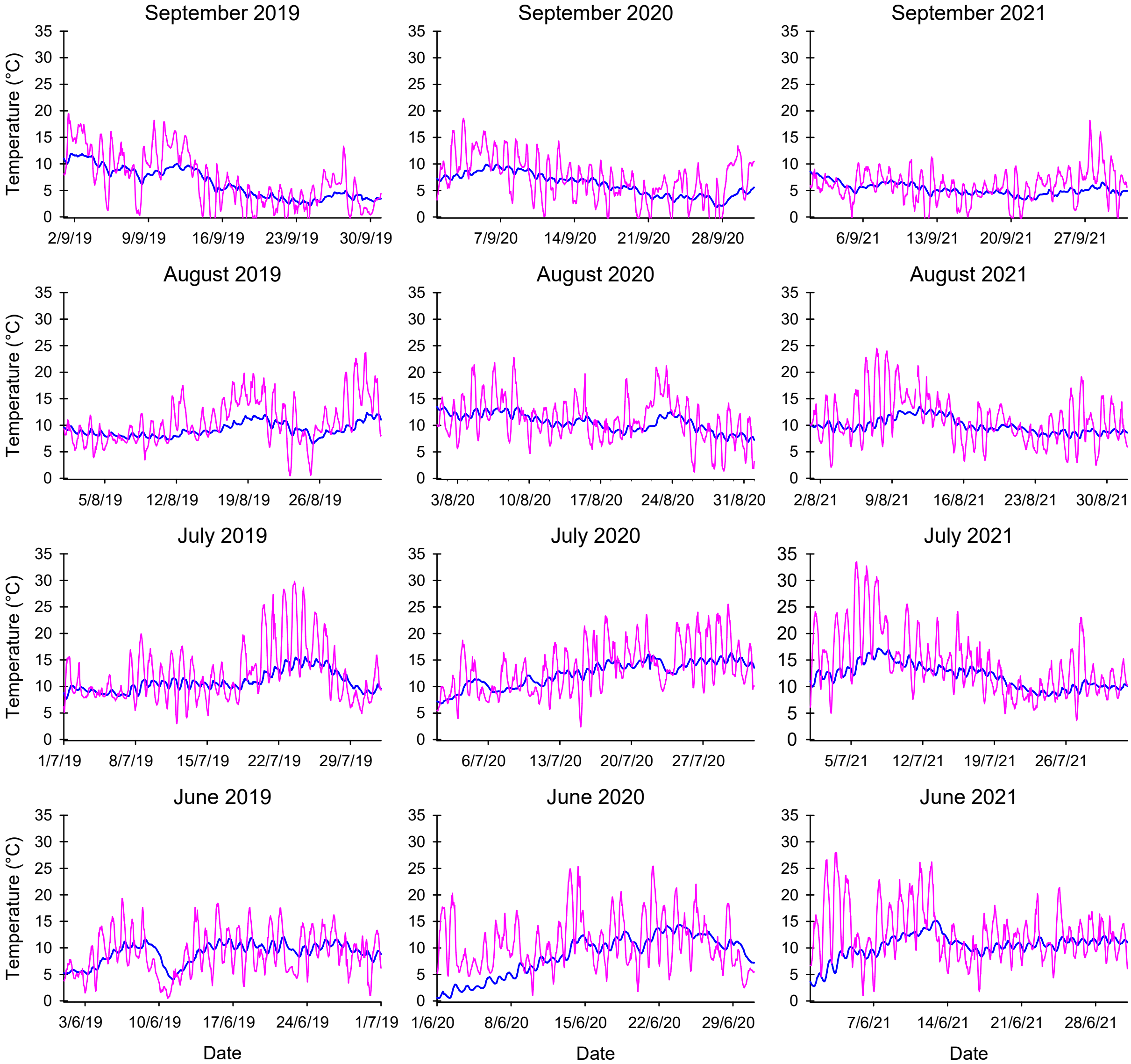


Figure 27. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Vidisjohka (brook in Tana) the years 2019, 2020 and 2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

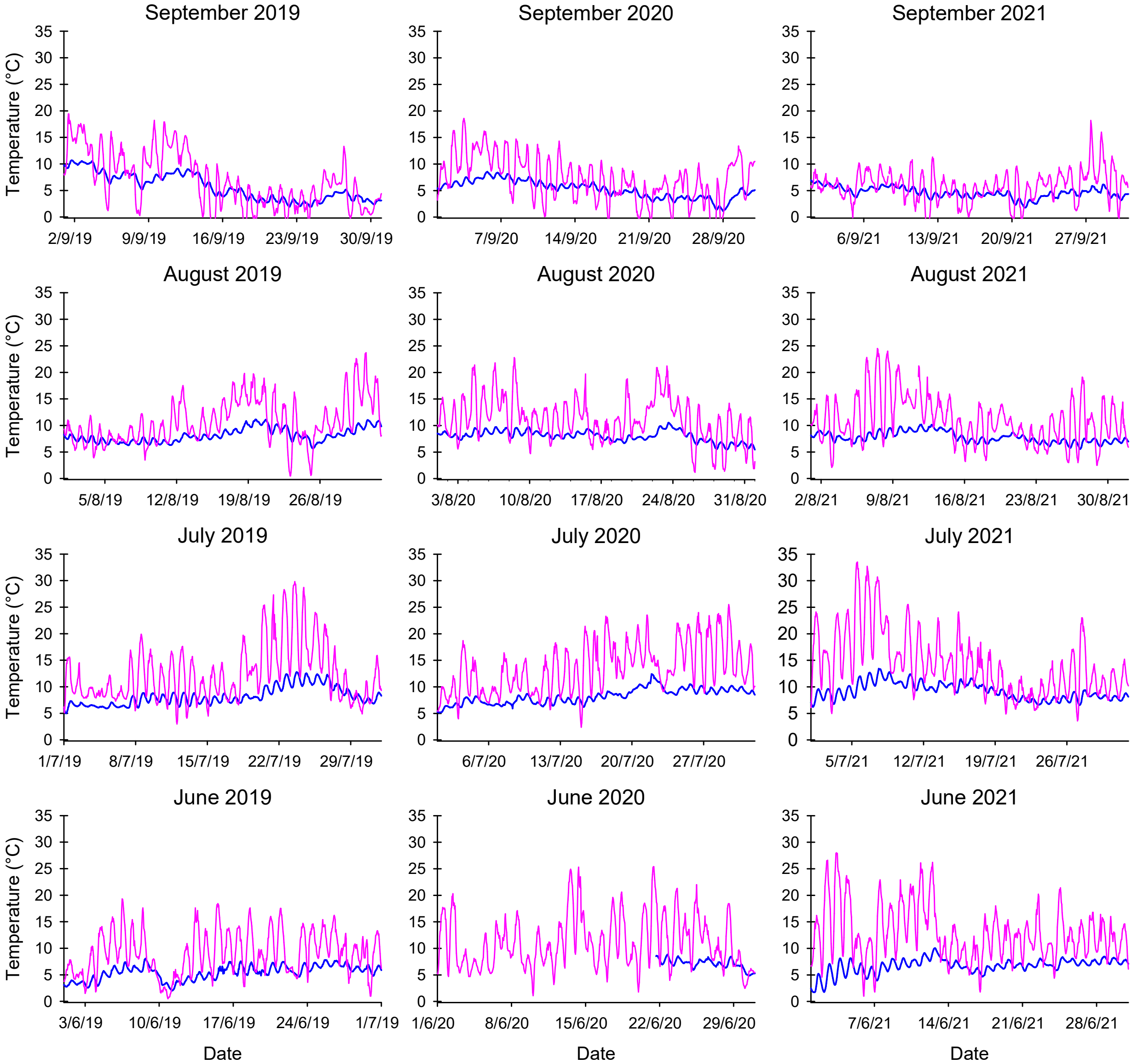


Figure 28. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Äimäjoki (brook in Tana) the years 2019, 2020 and 2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

In the River Tana watershed, there are a lot of small brooks and creeks running directly into the Tana mainstream or into the numerous salmon running tributaries. Brooks are running in small valleys between mountains, some have steep walls in their sides, some have mountain birches covering the creeks and some are running in open mountain areas without any canopy. All of these factors can affect the water temperature variations between brooks.

The brooks Vidisjohka, Äimäjoki and Rassijoki have cold waters mainly due to their situations in deep and sheltered valleys. Therefore, their water temperatures do not have clear hourly variations like the rivers Yläseitikkojoki, Puksaljoki and Leppäjoki do.

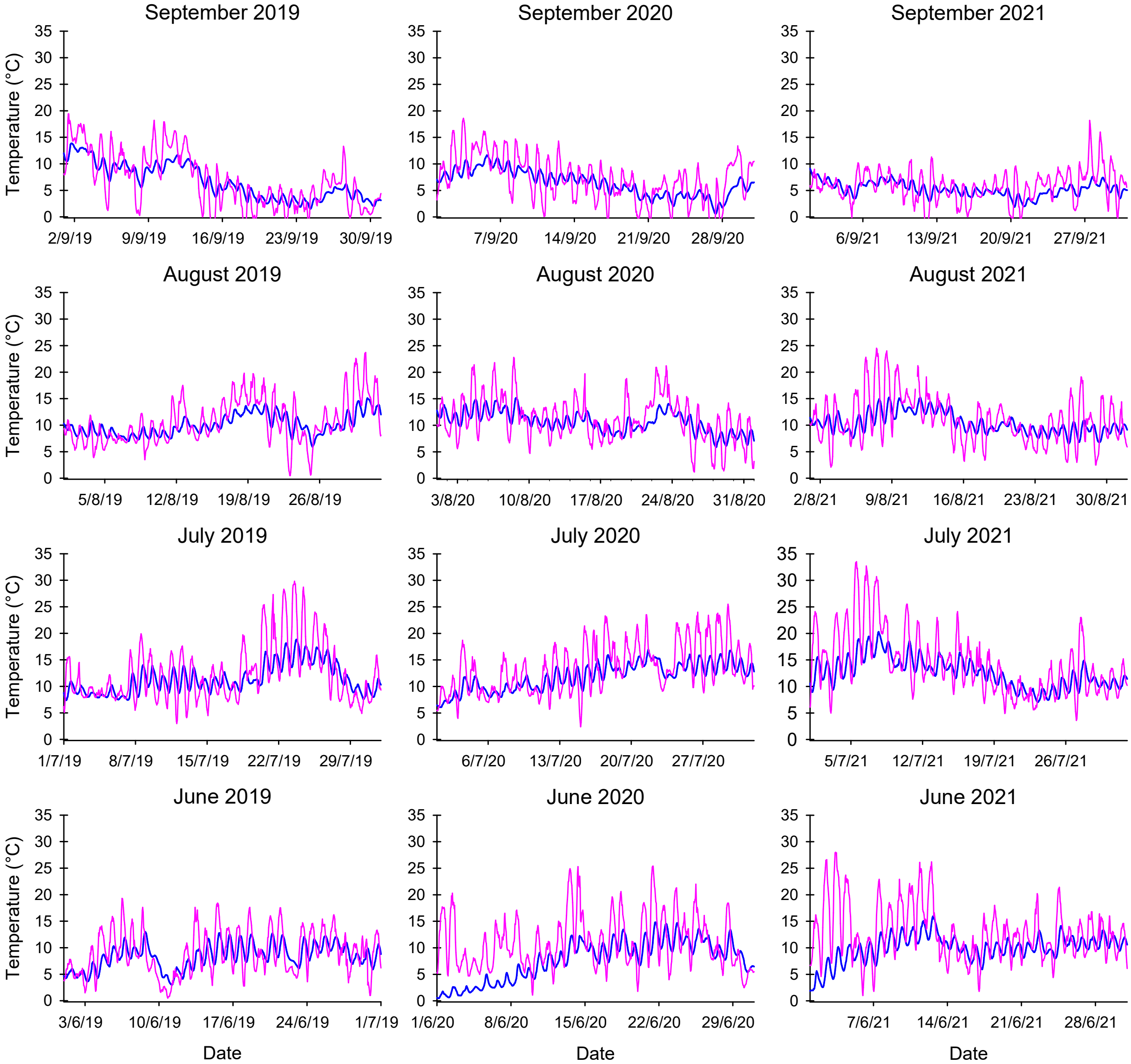


Figure 29. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Yläseitikkojoki (brook in the tributary Utsjoki) in the years 2019, 2020 and 2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

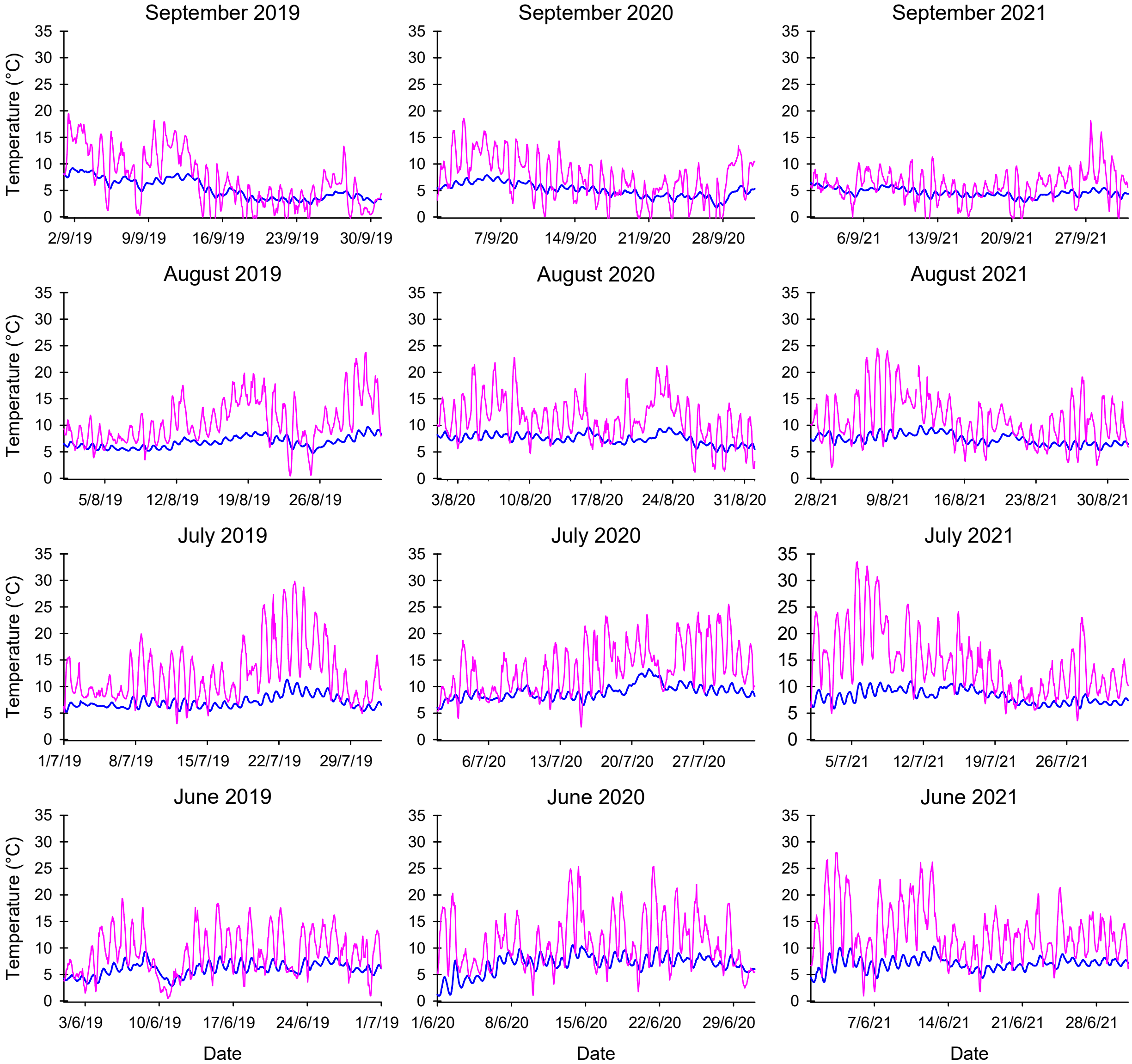


Figure 30. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Rassijoki (brook in the tributary Utsjoki) in the years 2019, 2020 and 2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

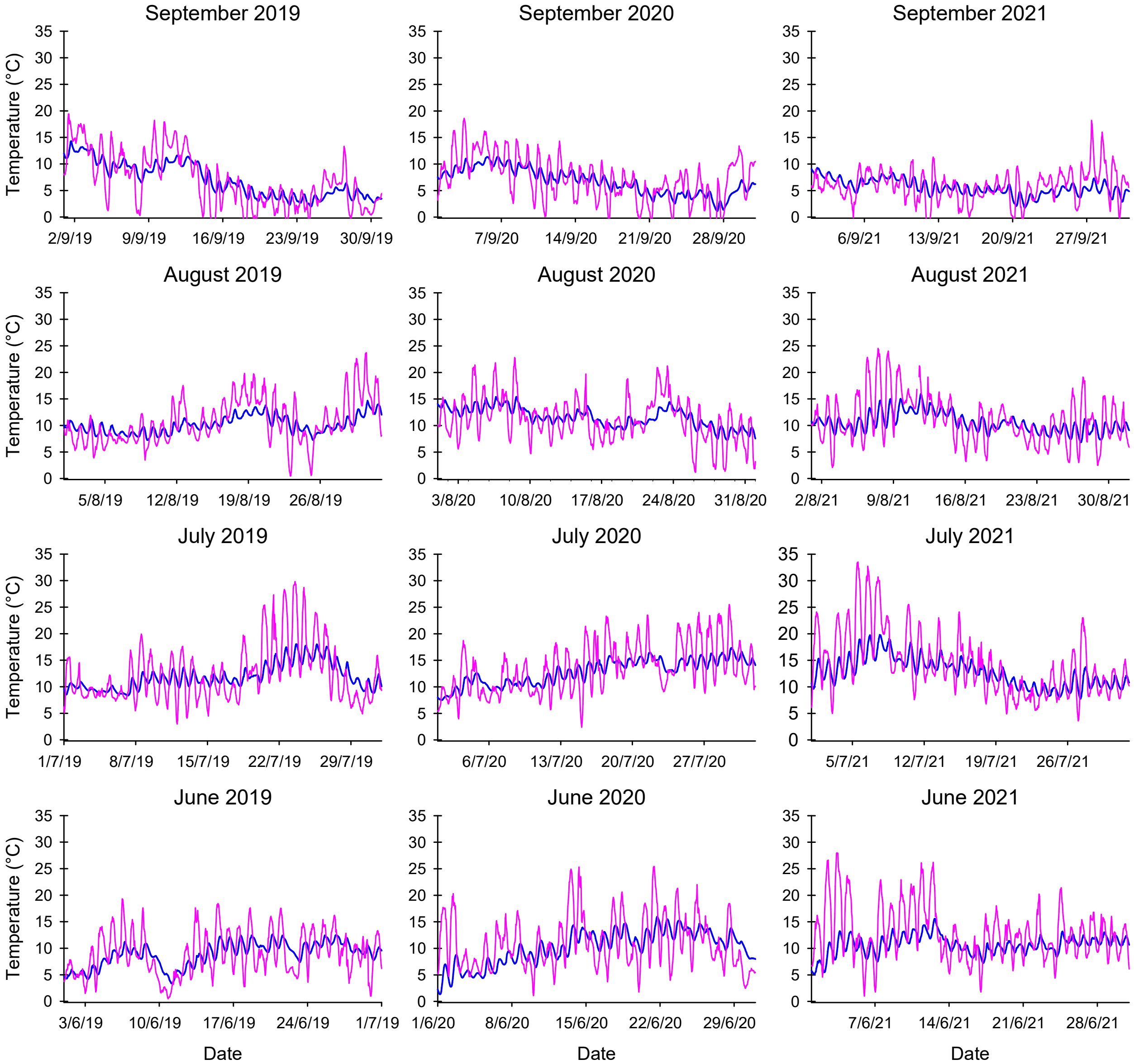


Figure 31. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Puksaljoki (brook in the tributary Utsjoki) in the years 2019, 2020 and 2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

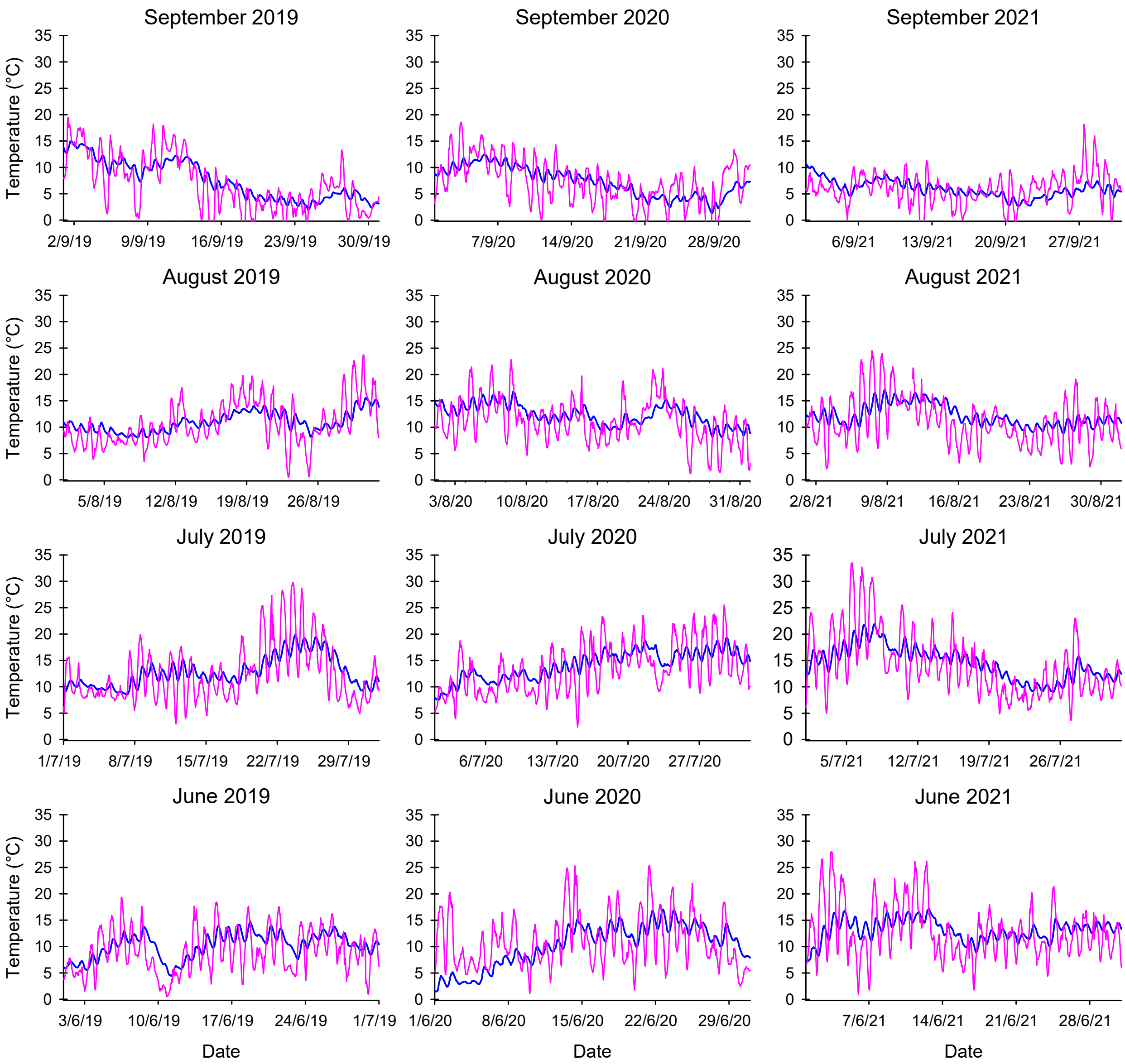


Figure 32. Hourly air temperature (pink curve) in Kevo, Utsjoki, and water temperature (blue curve) synchrony in summer months in the River Leppäjoki (brook in the tributary Utsjoki) in the years 2019, 2020 and 2021. Source; Finnish Meteorological Institute, Luke (Utsjoki).

4. Water temperatures in the spawning ground of salmon from egg fertilization in October to the end of the first year as 0+ -old juvenile (yearling)

Atlantic salmon spawn in the River Tana watershed from the second half of September to the middle of October. In small tributaries the spawning usually takes place from the middle of September to the end of September because of colder water temperatures in autumn than in the large tributaries and in the headwaters (rivers Iesjohka, Karasjohka, Anarjohka, Tana, Utsjoki mainstream). In large headwaters the spawning usually takes place during the second week of October. This is the case in the lower sections of the river Utsjoki, where water temperatures are warmer later in autumn than in upper sections due to large lake Mantojärvi.

In the spawning period, second week of October in the year 2012, water temperature was around 5 °C. It thereafter declined gradually to 1.8 °C towards the end of October (Fig. 33). Water temperature continued to gradually decline, reaching 1 °C on 8th November and 0.13 °C on 27. November. From 28. November there was bottom ice covering all the stones in the river until 24. December and water temperature was at that time below 0 °C (c. -0.1 °C). Thereafter water temperature stayed +0.01°C until 19. April. On 3. May water temperature was for the first time +1 °C that year.

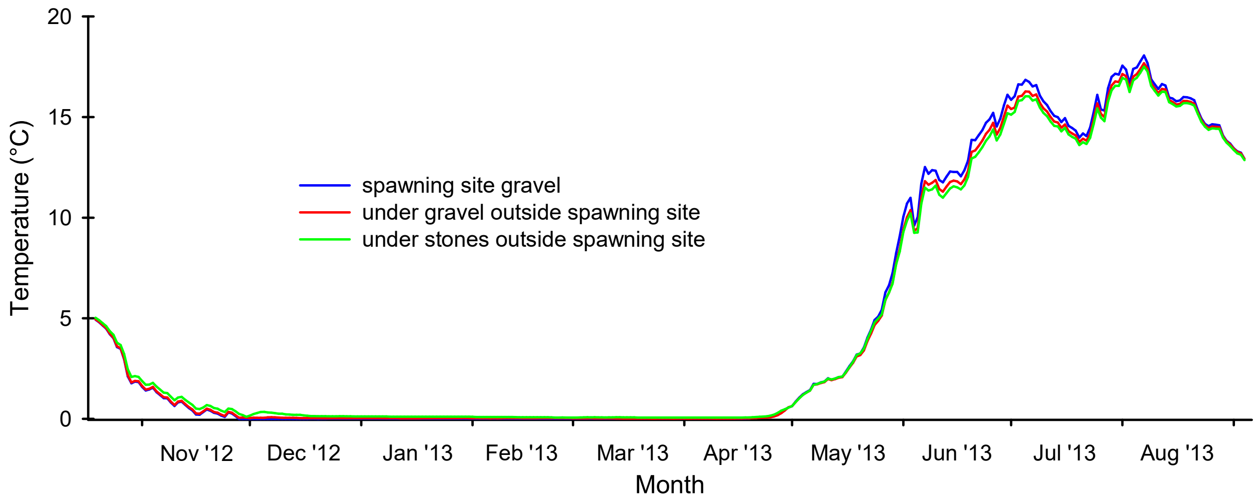


Figure 33. Water temperature in the lower areas of the tributary river Utsjoki in Tana watershed. Blue curve indicates water temperatures in the spawning site under the uppermost gravel layer. Source; Luke (Utsjoki).

5. Snow cover indicates the length of cold winter period

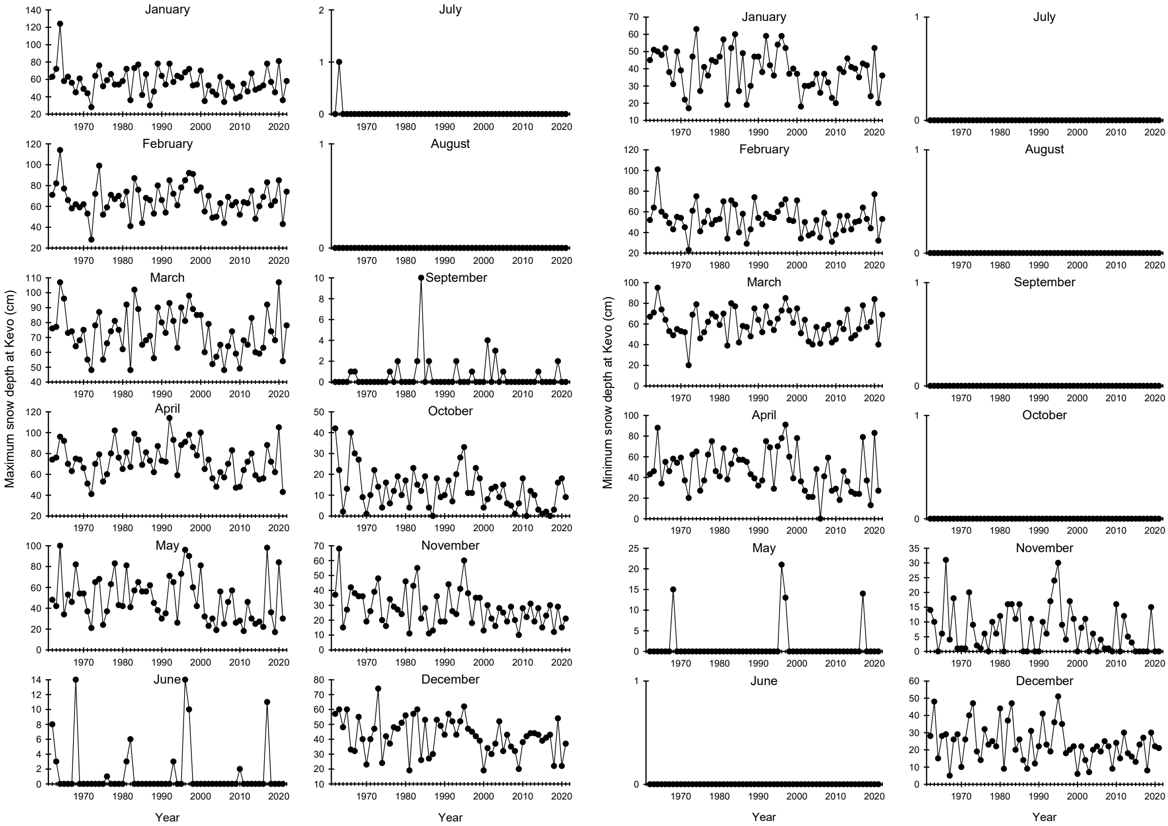


Figure 34. Maximun depth (cm) of snow cover in each month (on the left) and minimum depth (cm) of snow cover in each month (on the right). Source; Finnish Meteorological Institute.

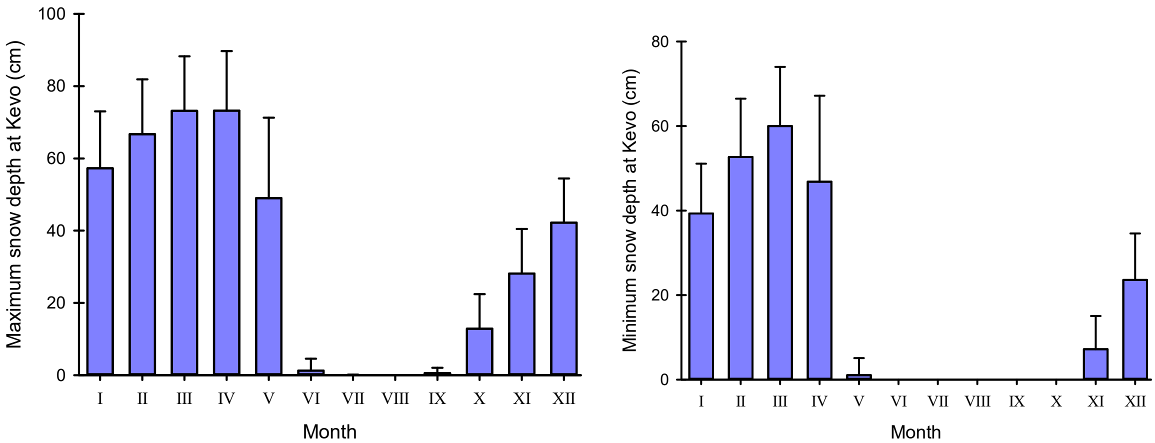


Figure 35. Maximum snow depth (cm, SD) (on the left) and minimum snow depth (cm, SD) (on the right) measured in each month in the period of the years 1962-2021. Source; Finnish Meteorological Institute.

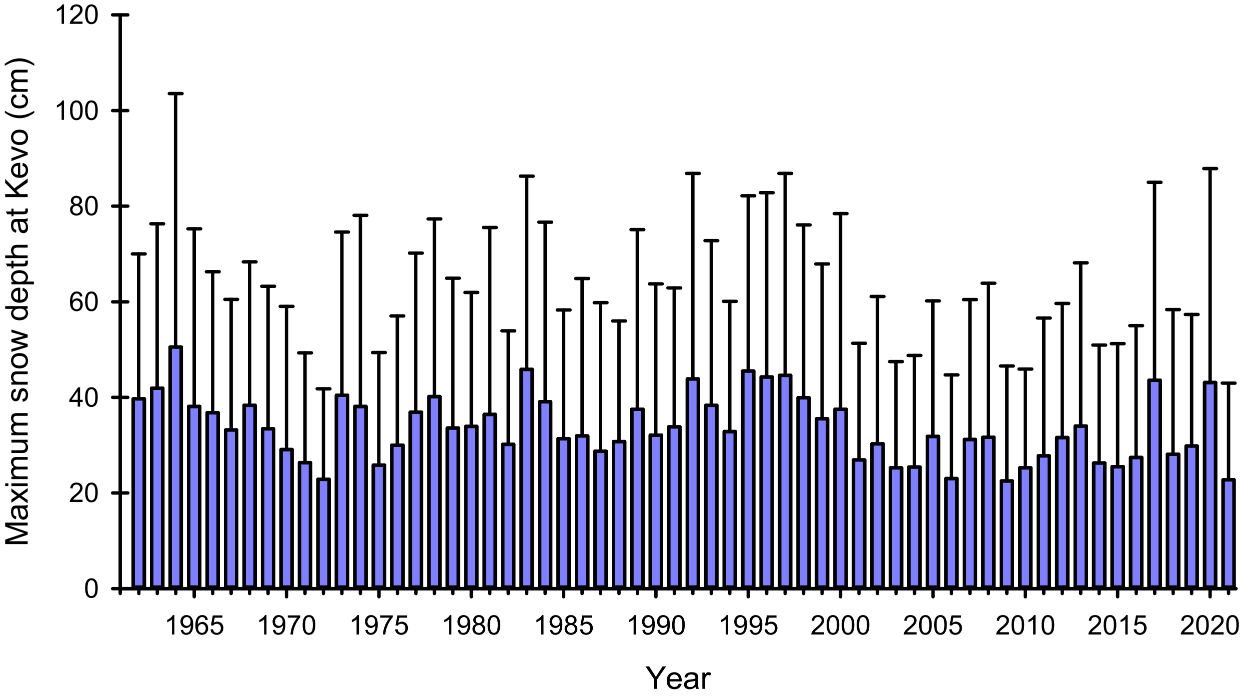


Figure 36. Mean maximum annual snow depth (cm, SD) for those months and days when snow cover has been measured. Source; Finnish Meteorological Institute.

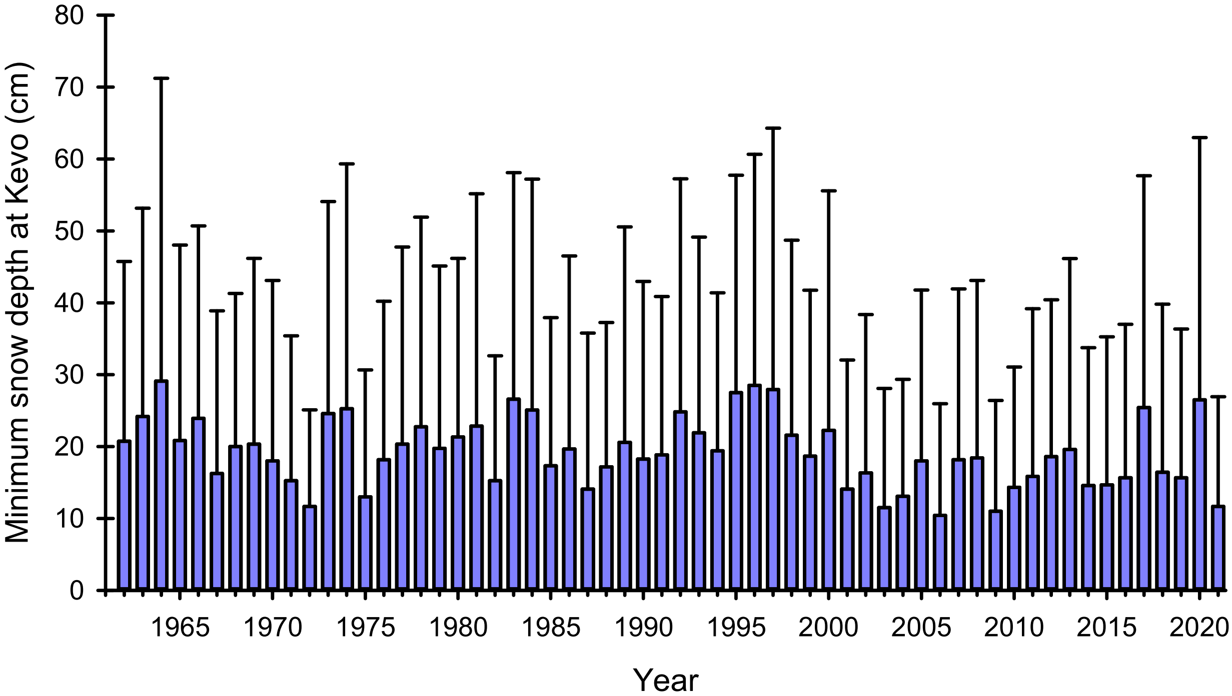


Figure 37. Mean minimum annual snow depth (cm, SD) for those months and days when snow cover has been measured. Source; Finnish Meteorological Institute.

6. Precipitation measured from the snow and rain is important for discharge in rivers

Monthly precipitation in Kevo station has been varying a lot over the past 60 years. There is no indication that air temperature changes have increased or decreased annual precipitation (Fig. 38). Also, the annual precipitation calculated from the mean monthly precipitation values indicate only the values being from 25 cm to 50 cm (Fig 39). Most from the annual precipitation comes during the three summer months between June and August (Fig. 40).

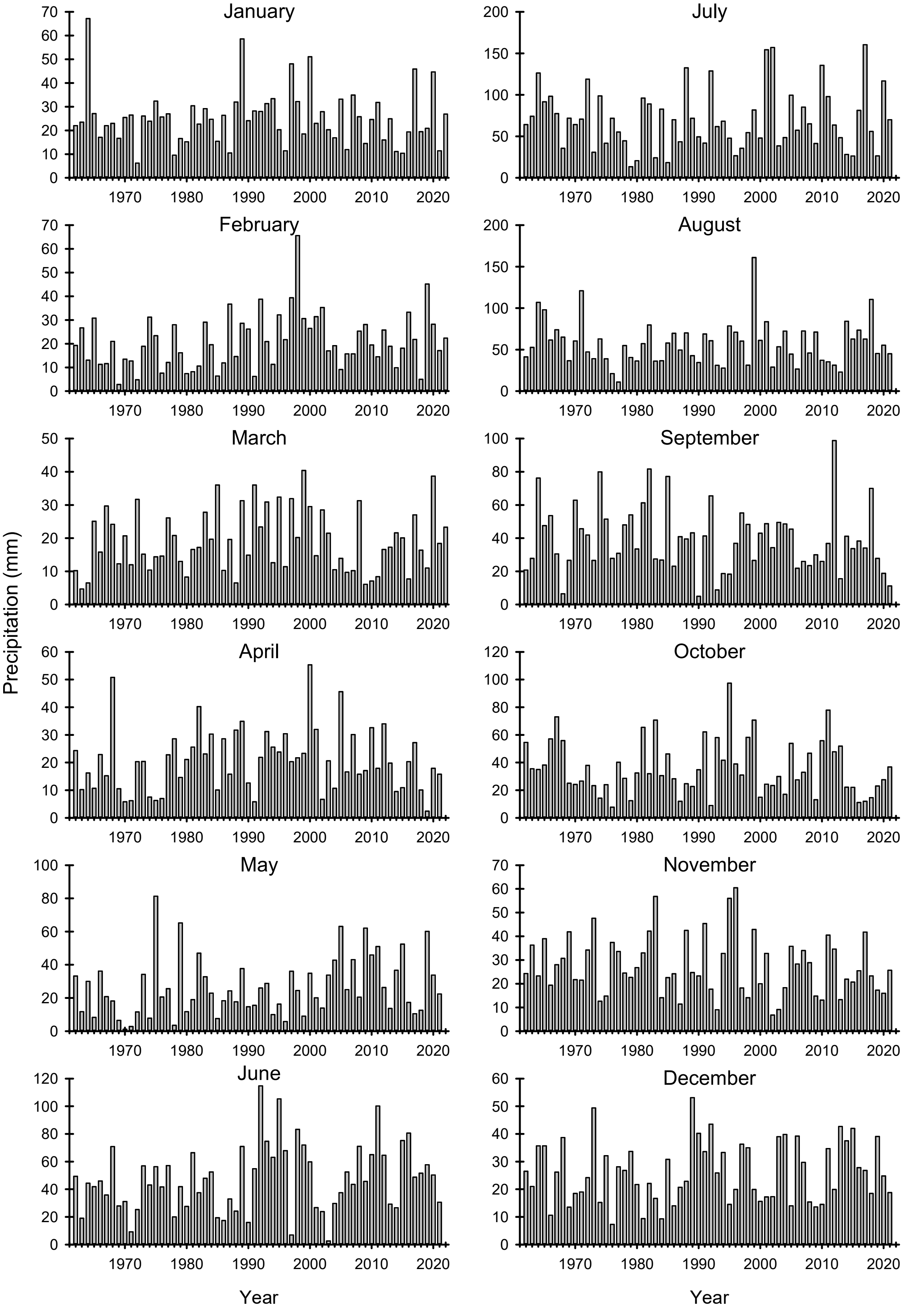


Figure 38. Monthly precipitation (mm) at Kevo Station, Utsjoki, in the River Tana watershed. Source; Finnish Meteorological Institute.

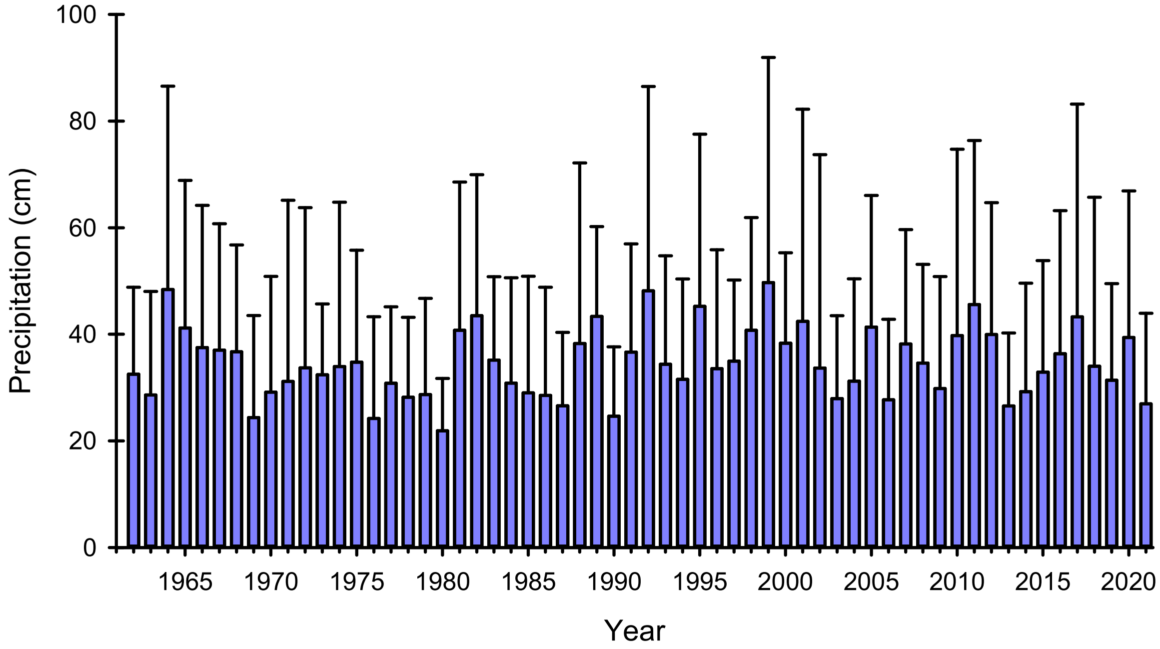


Figure 39. Annual precipitation (cm, SD) at Kevo Station, calculated yearly from the monthly mean values. Source; Finnish Meteorological Institute.

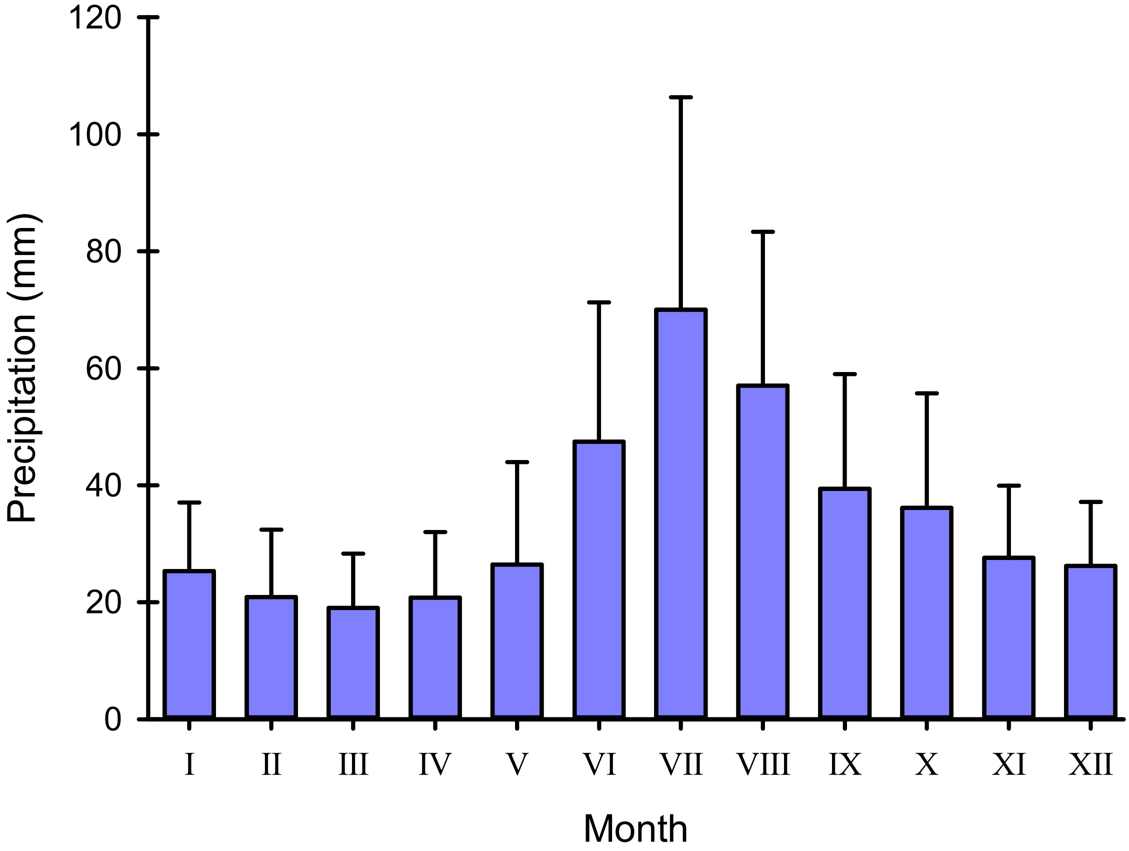


Figure 40. Monthly mean precipitation (mm, SD) at Kevo Station calculated from the monthly mean values in the period of 1962-2021. Source; Finnish Meteorological Institute.

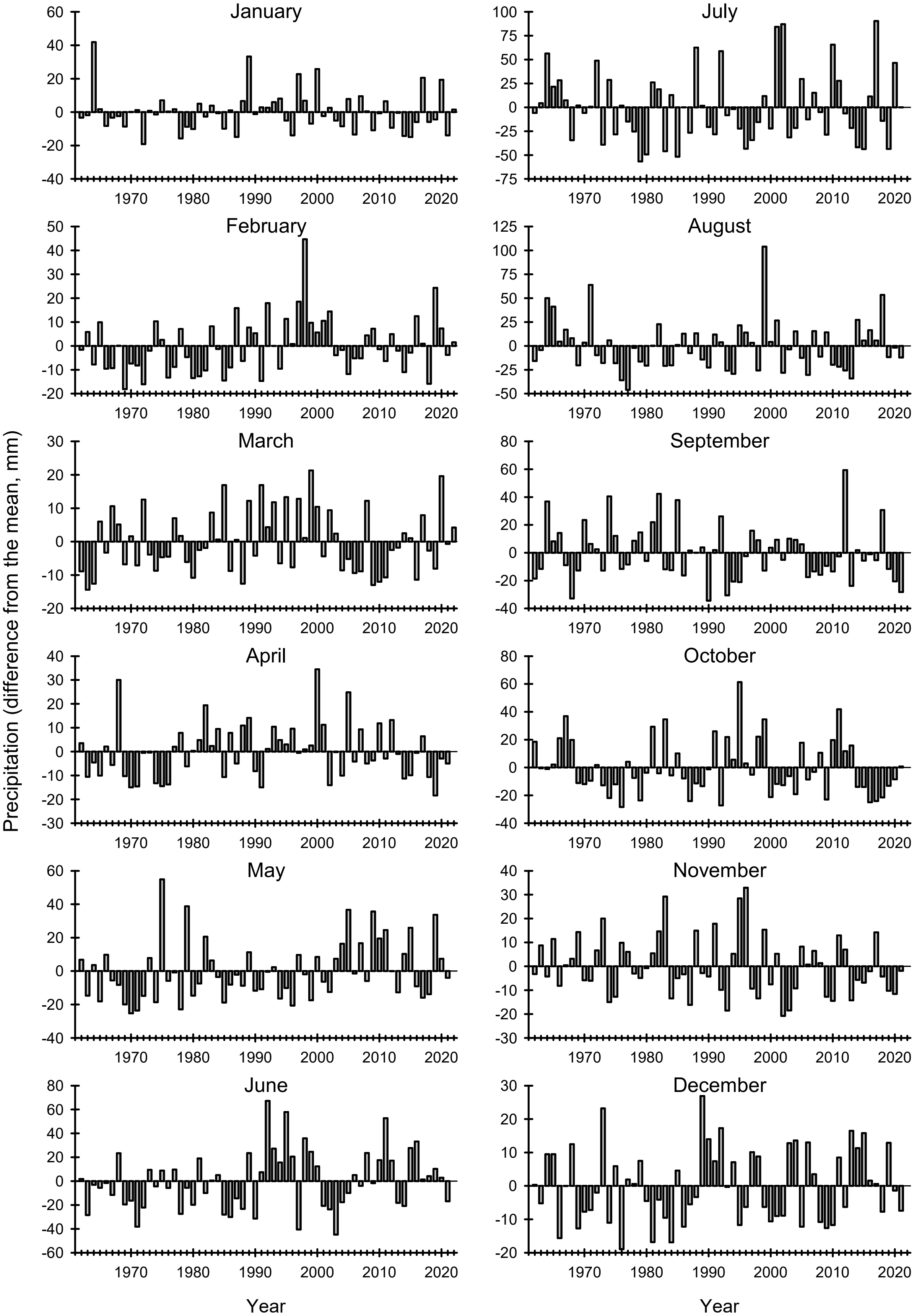


Figure 41. Monthly deviations (mm) for each month of the year from the long-term monthly mean precipitation at Kevo Station, Utsjoki in Tana watershed. Source; Finnish Meteorological Institute.

7. Changes in flow and water level can indicate climate changes and therefore disturb salmon migrations and salmon fishery

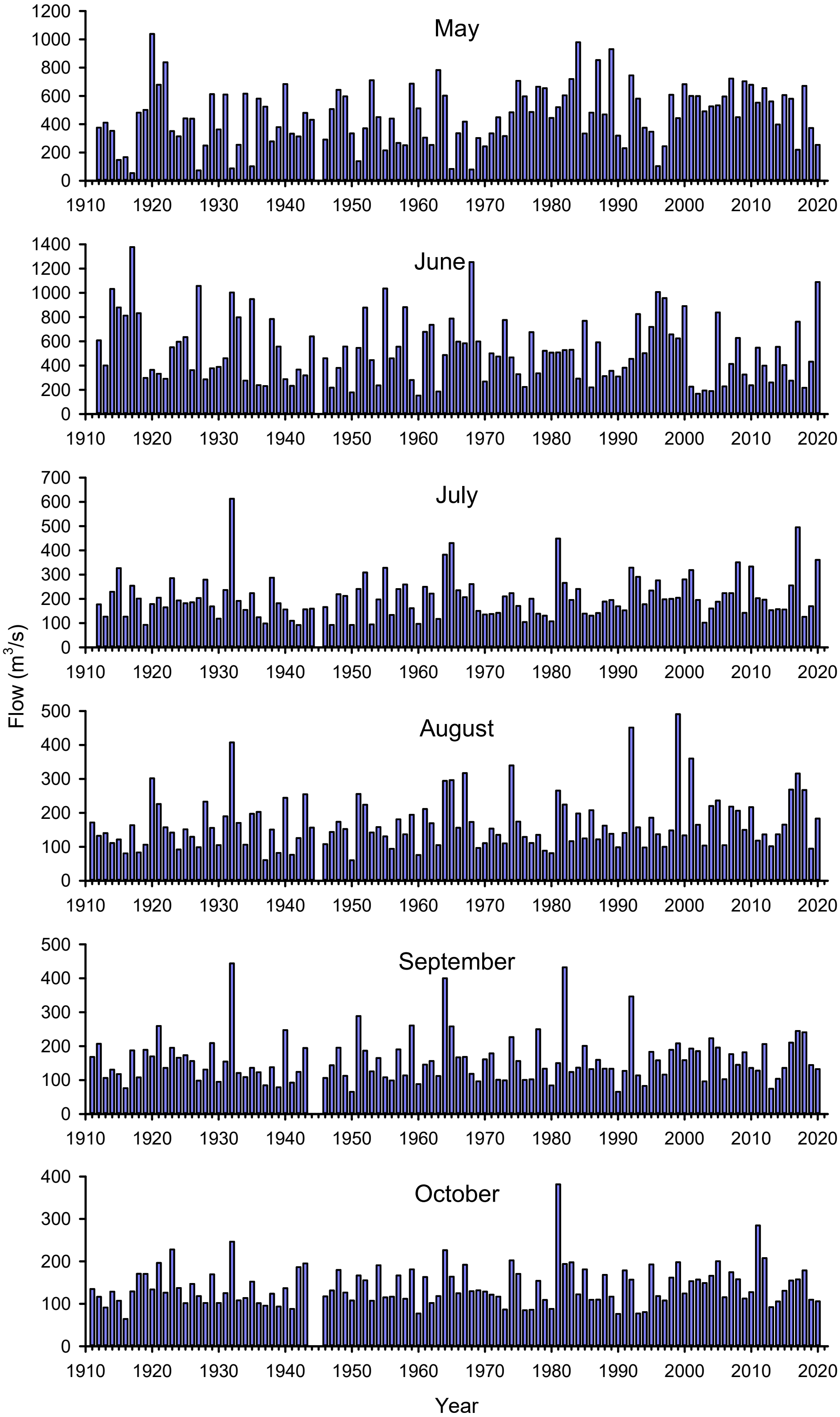


Figure 42. Long-term monthly mean water flows in summertime in the River Tana (in Polmak) in the years 1910-2020. Source; NVE, Norway.

Long-term data (110 years) indicates large annual variations in the mean flows in all the summer months (Fig. 42). Figure 43 indicates that flows have not changed in the long-term during early salmon migration period in the end of May or in the beginning of June or during the spawning period in early October. Big annual variations are noticeable.

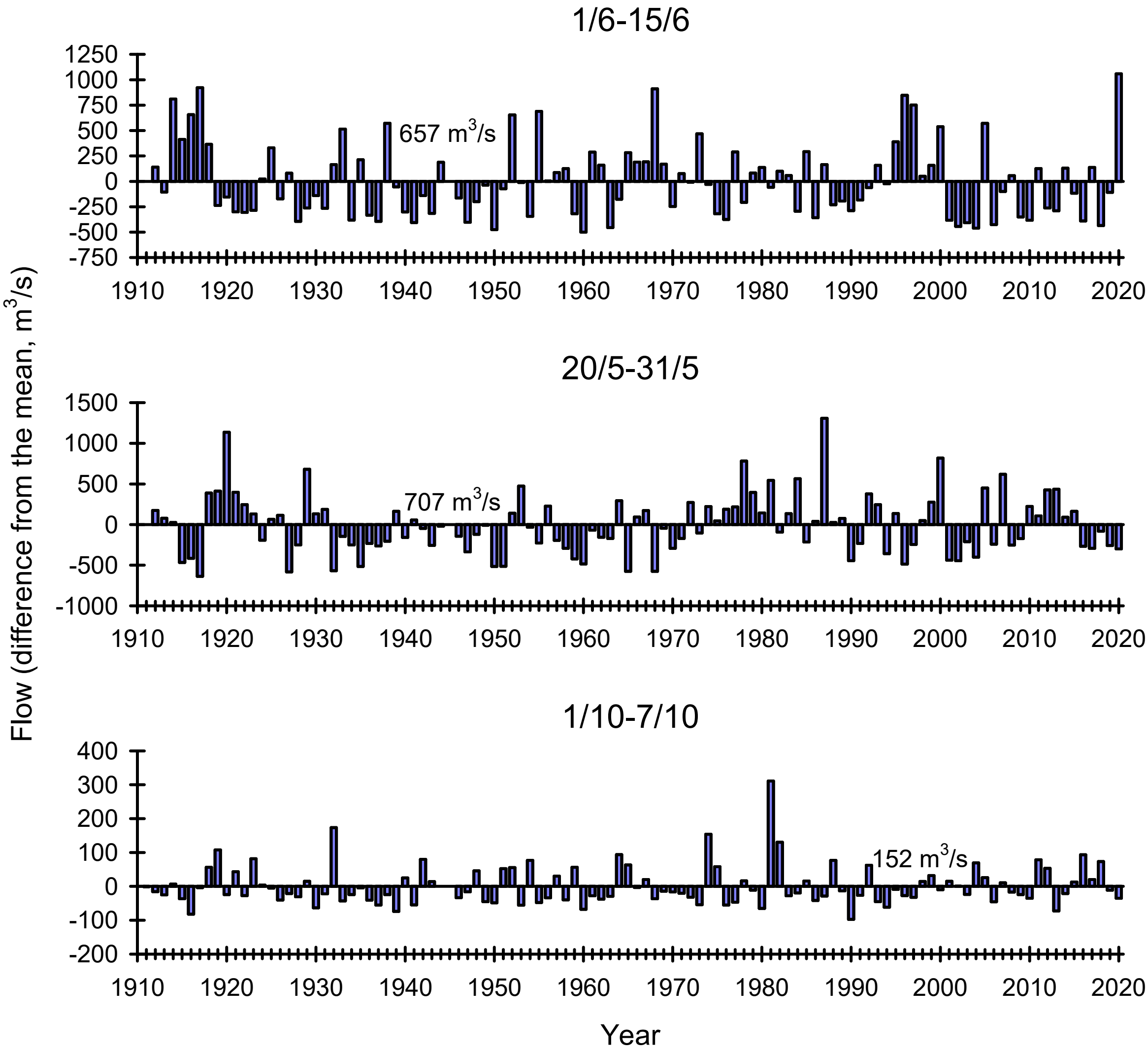


Figure 43. Annual deviations from the long-term mean flow values for selected time periods in the River Tana (Polmak). Source; NVE, Norway.

Water levels fluctuates during the summer period due to precipitation. In all the years high flows are occurring in May or early June due to snow melting (Figs. 44 and 45). Some years water levels are rising in July or August, ceasing the traditional weir and gillnet fishery even for weeks.

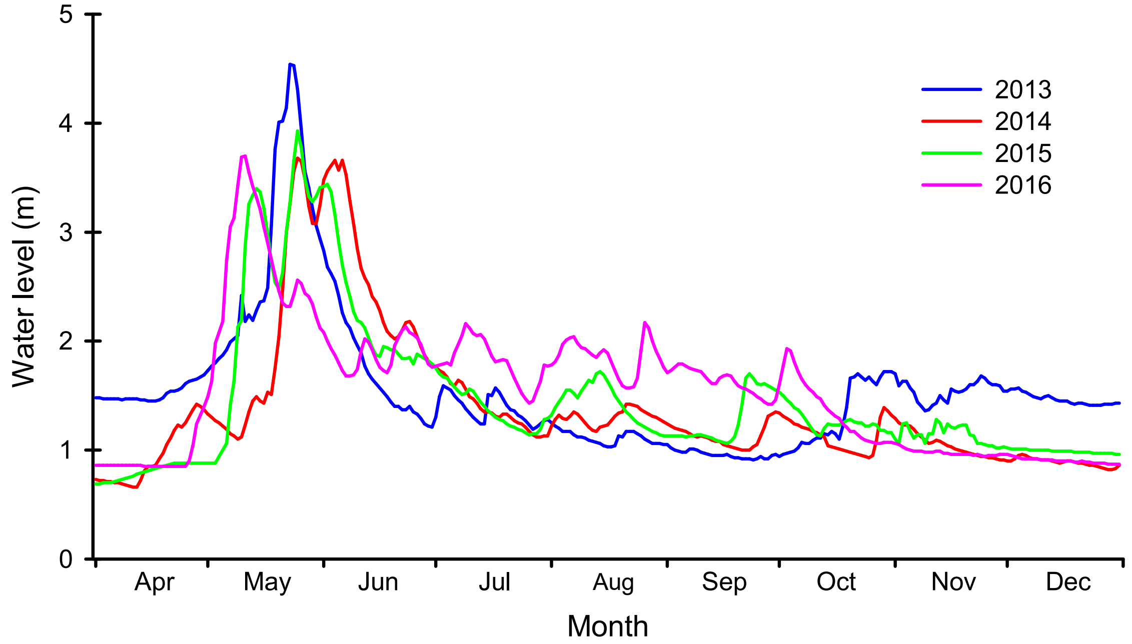


Figure 44. Annual daily water level variations from April to the end of the year in the River Tana (Polmak). Source; NVE (Norway).

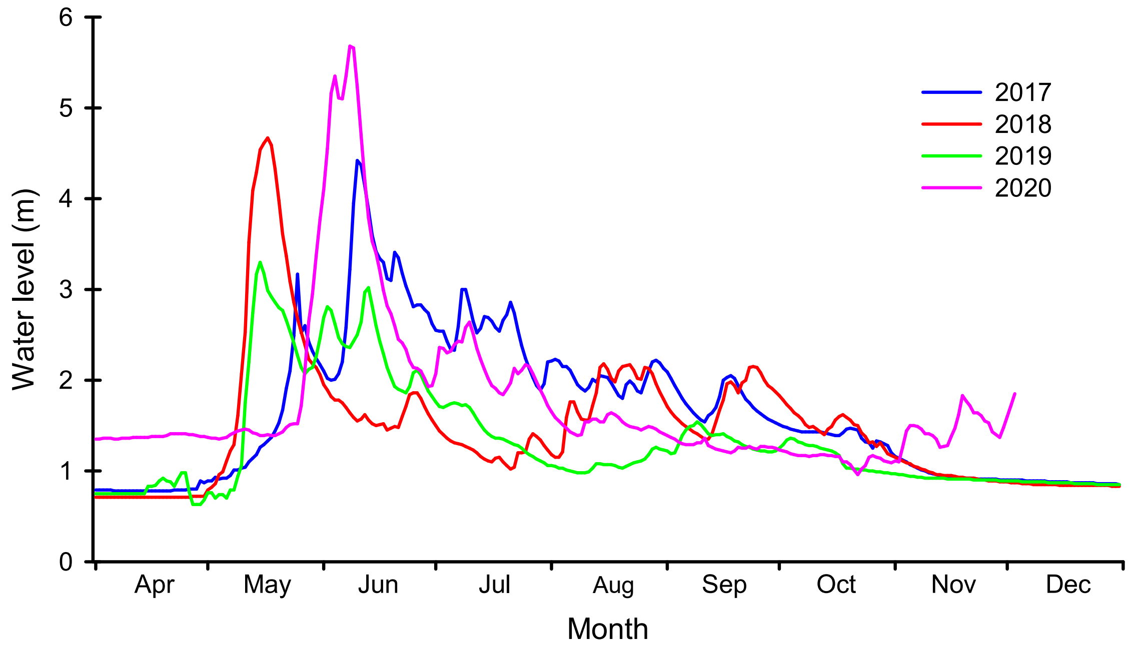


Figure 45. Annual daily water level variations from April to the end of the year in the River Tana (Polmak). Source; NVE, Norway.

Water levels in the upper areas in the River Tana (Onnela in Finland) fluctuates like the water levels in the Polmak area (Fig. 46). High flows are occurring every year in May or early June, caused by the sudden snow smelting in the mountain areas. It has been quite unusual to have high water levels in the middle of the summer.

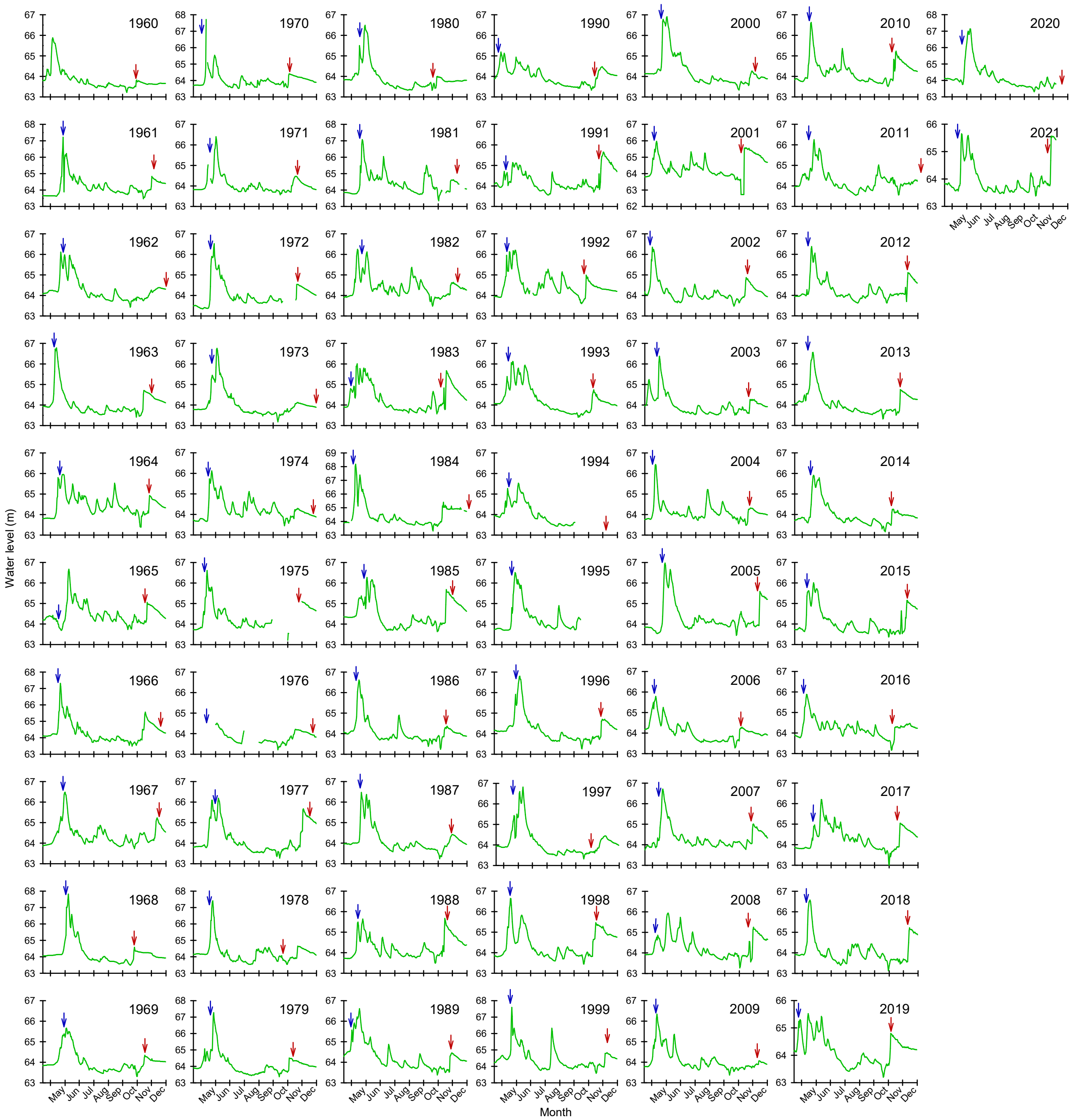


Figure 46. Daily water levels in the River Tana in the Onnela site in Finland from April to the end of the year in the years 1960-2021. Blue arrow indicates the date of ice- break up and red arrow the date of ice cover formation. Source; Finnish Environment Institute.

In the end of May and in June there has not been clear trends indicating long-term changes in the water levels, but annual variations have been obvious (Fig. 47).

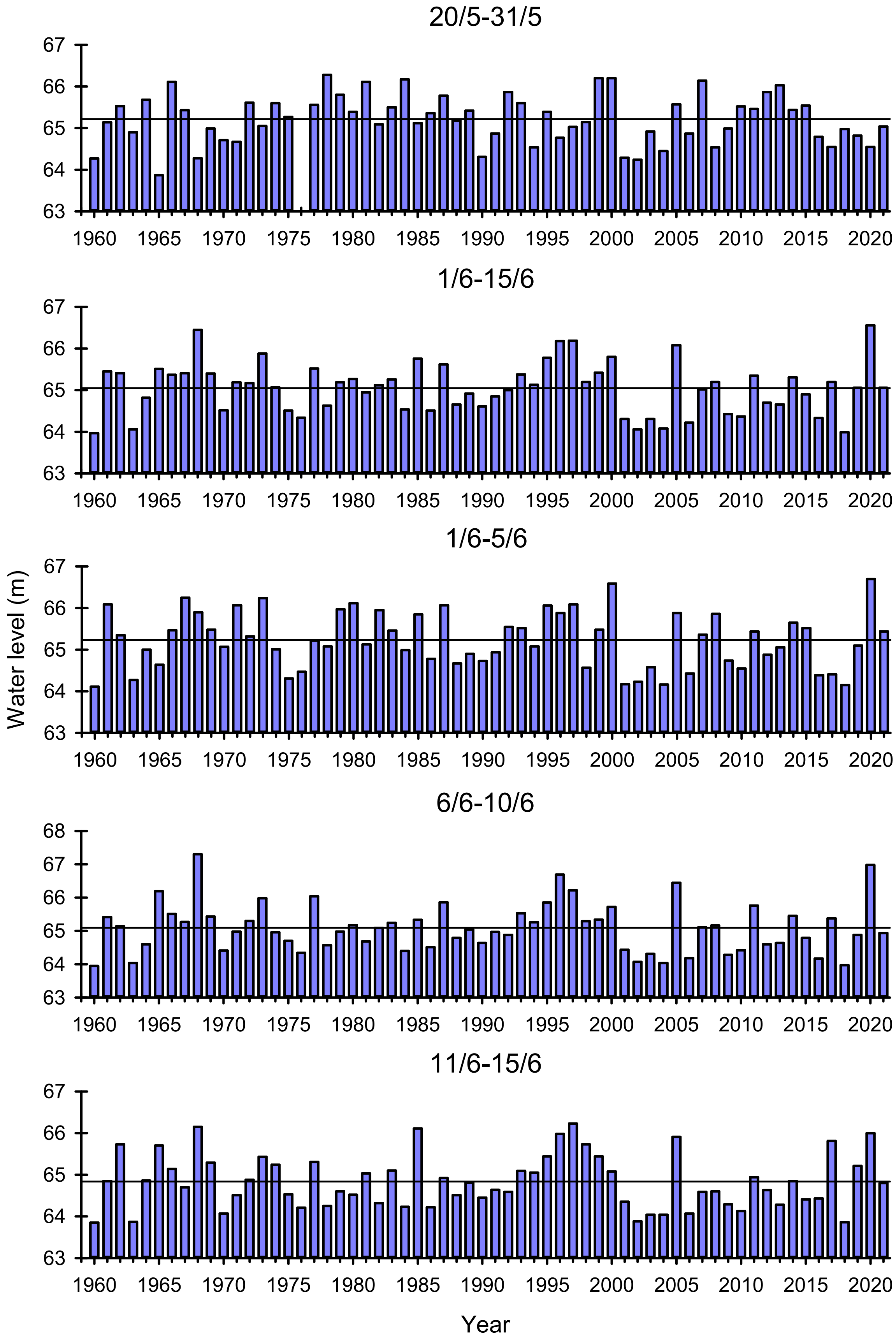


Figure 47. Annual water levels early in the summer in the River Tana (Onnela site, Finland) in the years 1960-2021. The line indicates the long-term mean. Source; Finnish Environment Institute.

Salmon spawn in the River Tana mainstem during the first half of October. Figure 48 shows that water levels are varying annually but, in general over the years deviations from the long-term mean have been rather small. High water levels early in October are harmful to the success for salmon spawning because salmon may spawn in sites close to shore lines, which can be destroyed by ice blocks during the winter or early next spring.

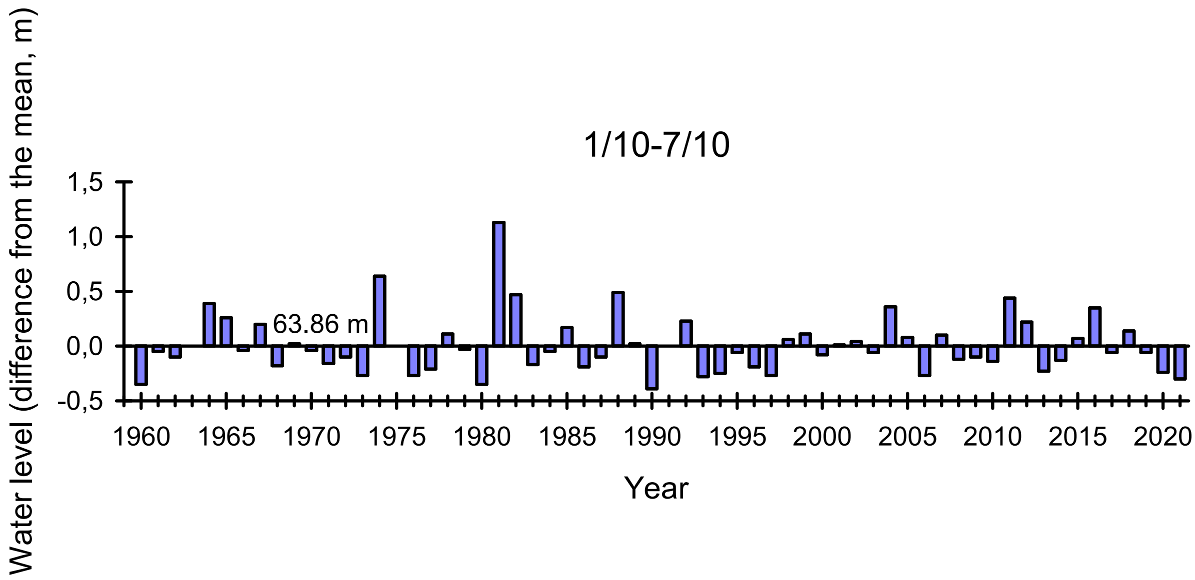


Figure 48. Water level deviations from the long-term mean values in the period 1.-7. October in the River Tana (Onnela site, Finland). Source; Finnish Environment Institute.

Figures 49, 50, 51 and 52 indicates the hourly water level and water temperature relationships in each month from May to November in the River Tana and in the River Anarjohka.

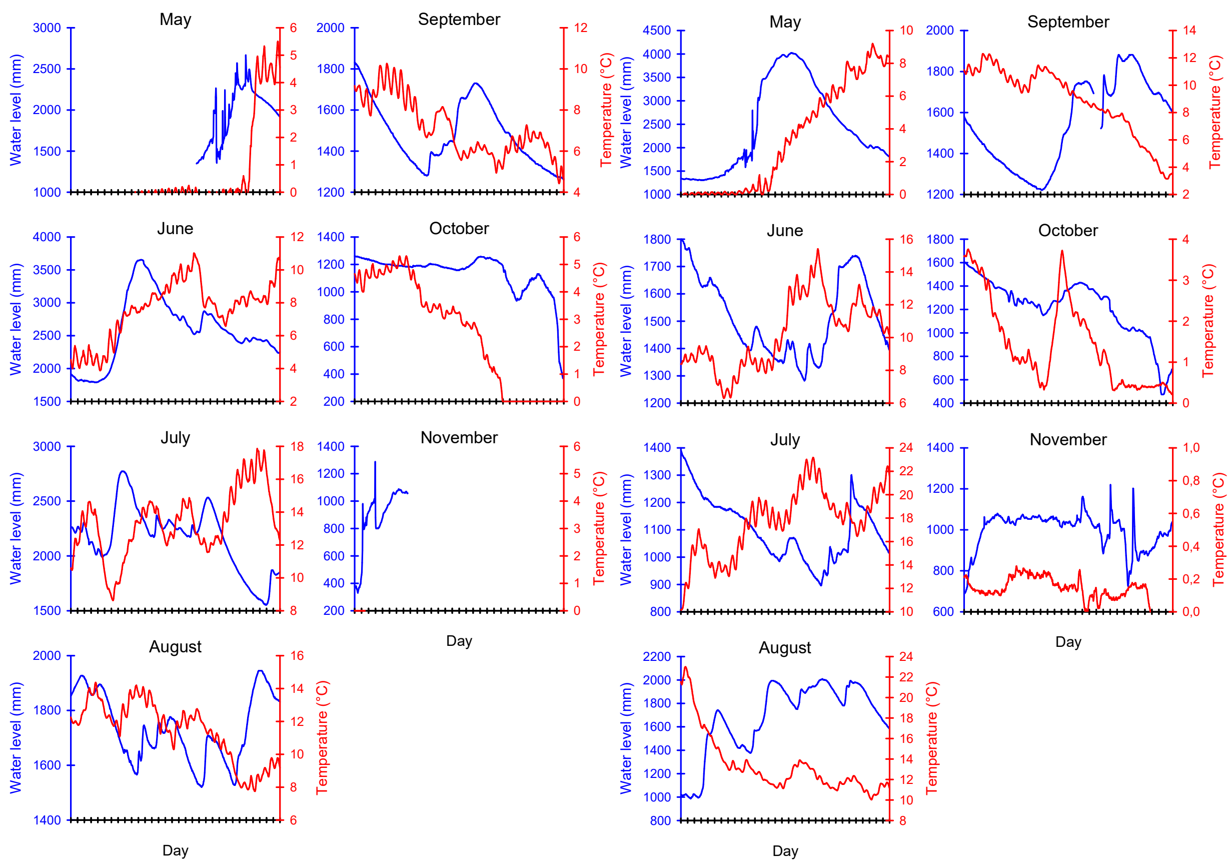


Figure 49. Hourly water levels (blue curve) in each summer month in the River Tana (Onnela, Finland) and water temperatures (pink curve) in the River Tana (Polmak) in the year 2017 (on the left side) and in the year 2018 (on the right side). Source; Finnish Environment Institute, NVE (Norway).

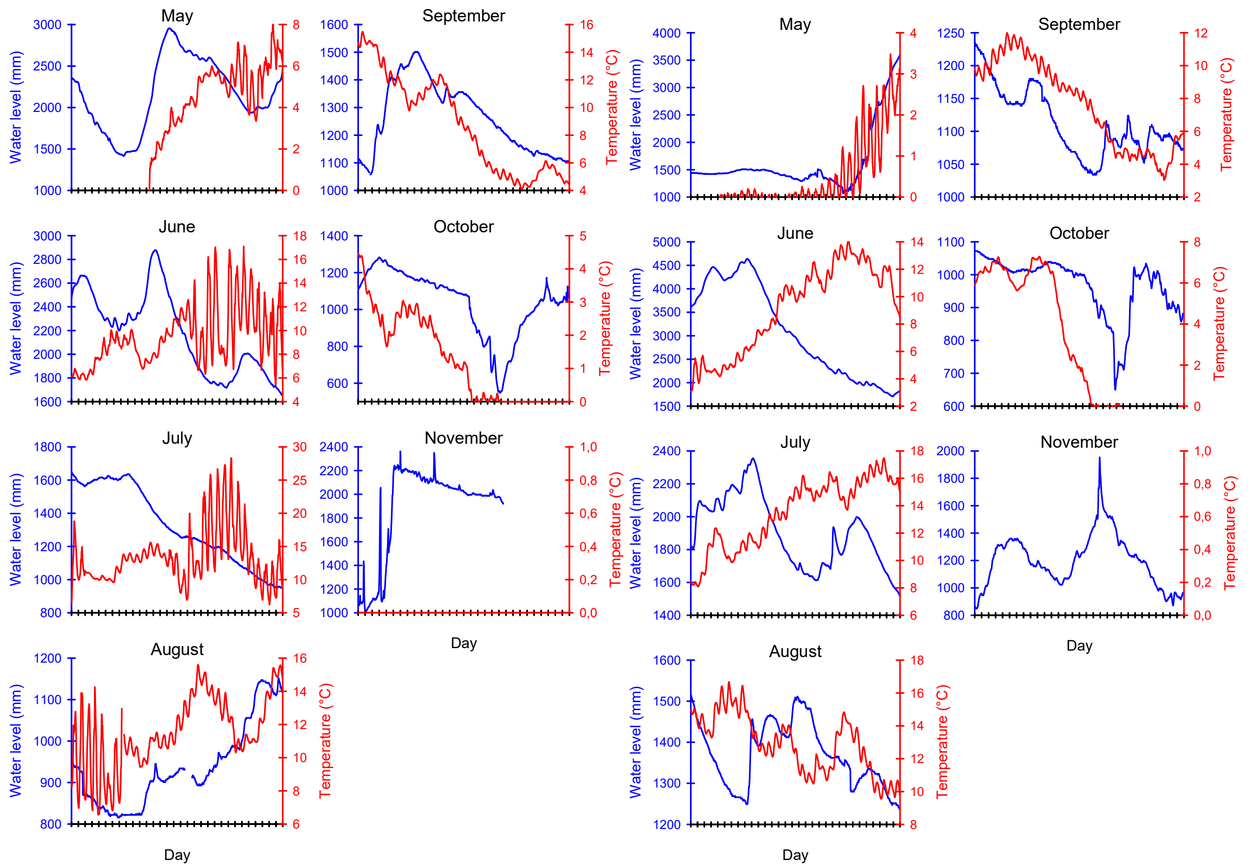


Figure 50. Hourly water levels (blue curve) in each summer month in the River Tana (Onnela, Finland) and water temperatures (pink curve) in the River Tana (Polmak) in the year 2019 (on the left side) and in the year 2020 (on the right side). Source; Finnish Environment Institute, NVE (Norway).

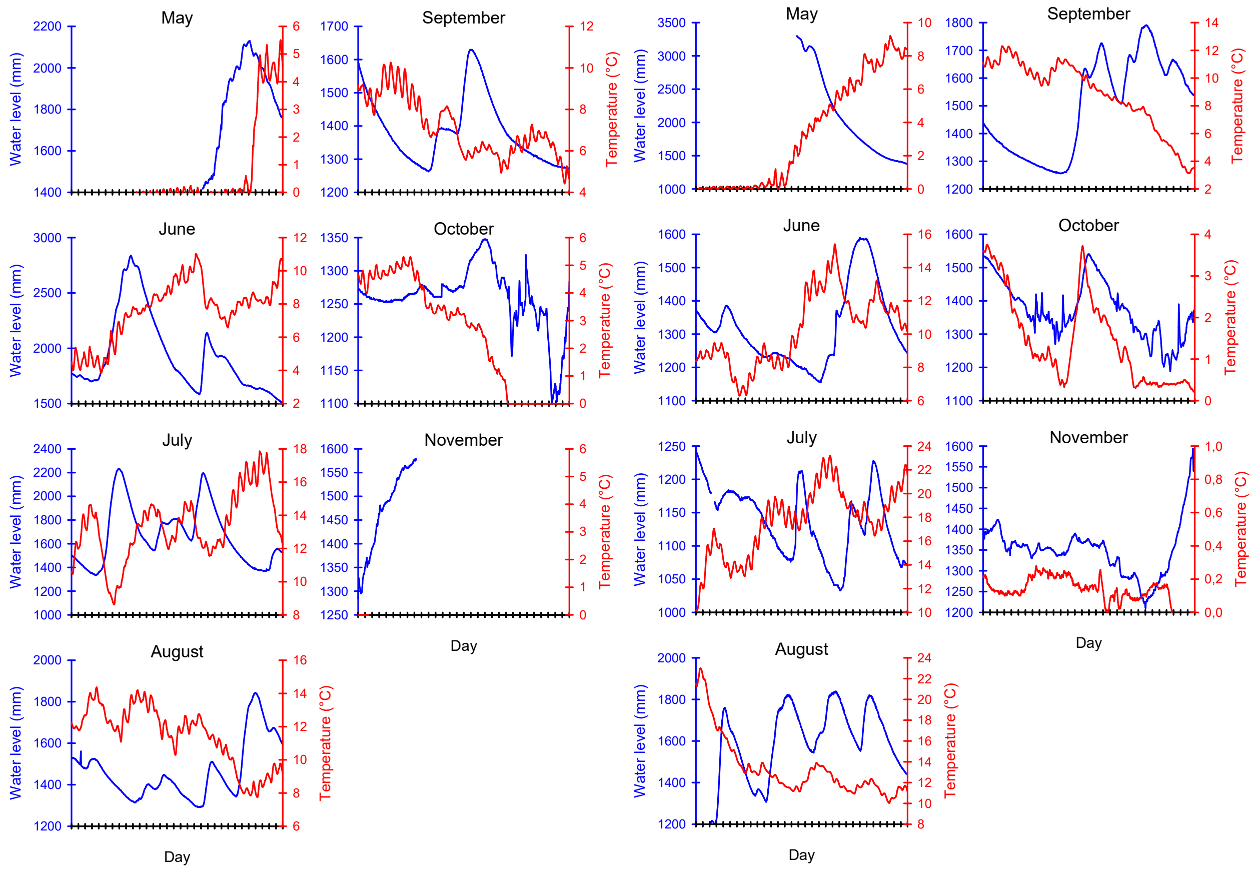


Figure 51. Hourly water levels (blue curve) in each summer month in the River Anarjohka and water temperatures (pink curve) in the River Tana (Polmak) in the year 2017 (on the left side) and in the year 2018 (on the right side). Source; Finnish Environment Institute, NVE (Norway).

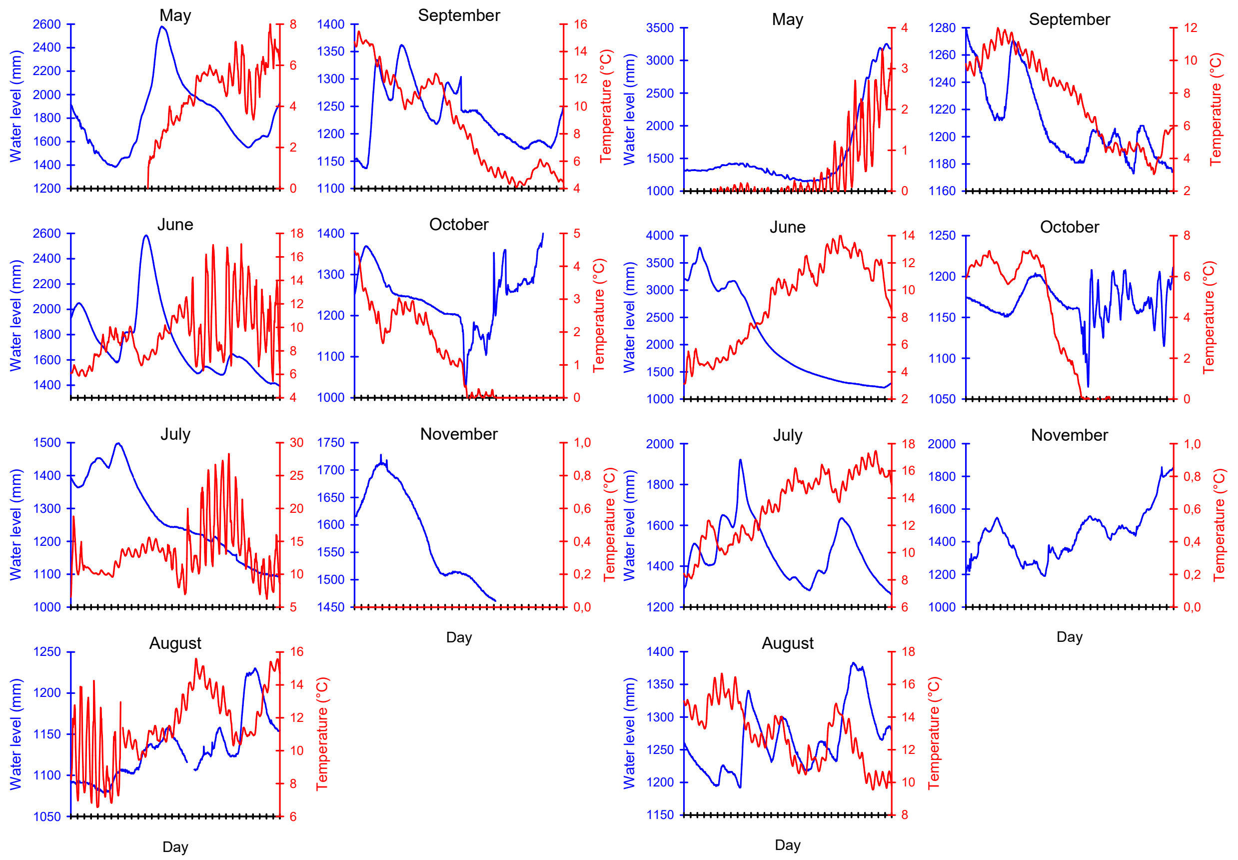


Figure 52. Hourly water levels (blue curve) in each summer month in the River Anarjohka and water temperatures (pink curve) in the River Tana (Polmak) in the year 2019 (on the left side) and in the year 2020 (on the right side). Source; Finnish Environment Institute, NVE (Norway).

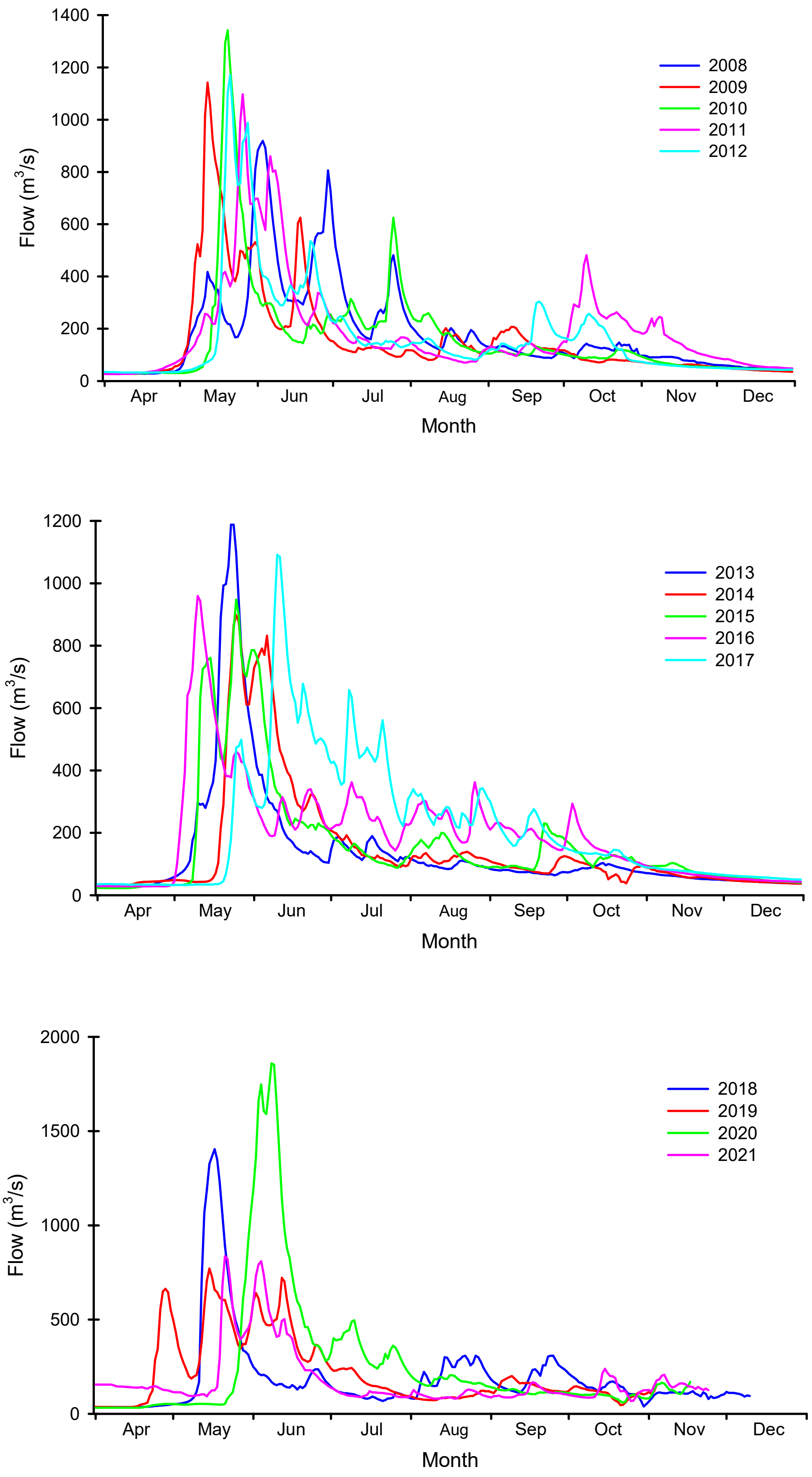


Figure 53. Daily water flows from April to the end of the year in the River Tana (Onnela, Finland) in the years 2008-2021. Source; Finnish Environment Institute.

8. Ice breaking- up date and freezing (=ice formation) on the way to change in long-term and affect to the catch timing of salmon in the river Tana watershed

The River Tana with its tributaries and brooks are usually covered by ice from the end of October or November to the middle of May. Figure 54 indicates the wide time period when ice breaking- up has taken place. Some few years ice breaking-up has happened in the end of April or even early in June.

Ice breaking-up dates in the Levajohka site has nowadays taken place earlier than in the end of the year 1880 (Fig. 55), although there have been huge annual variations. Earlier ice breaking-up has also been observed in another large northern river, Torniojoki, where data is available from 1750's and onwards (Fig 55). Also, in other sites there has been large annual variations in the ice breaking-up dates (Fig. 56). Nowadays it has been found that the exact ice breaking-up day has been difficult to observe because ice melting in the rivers has behaved differently compared to years when ice has been thick.

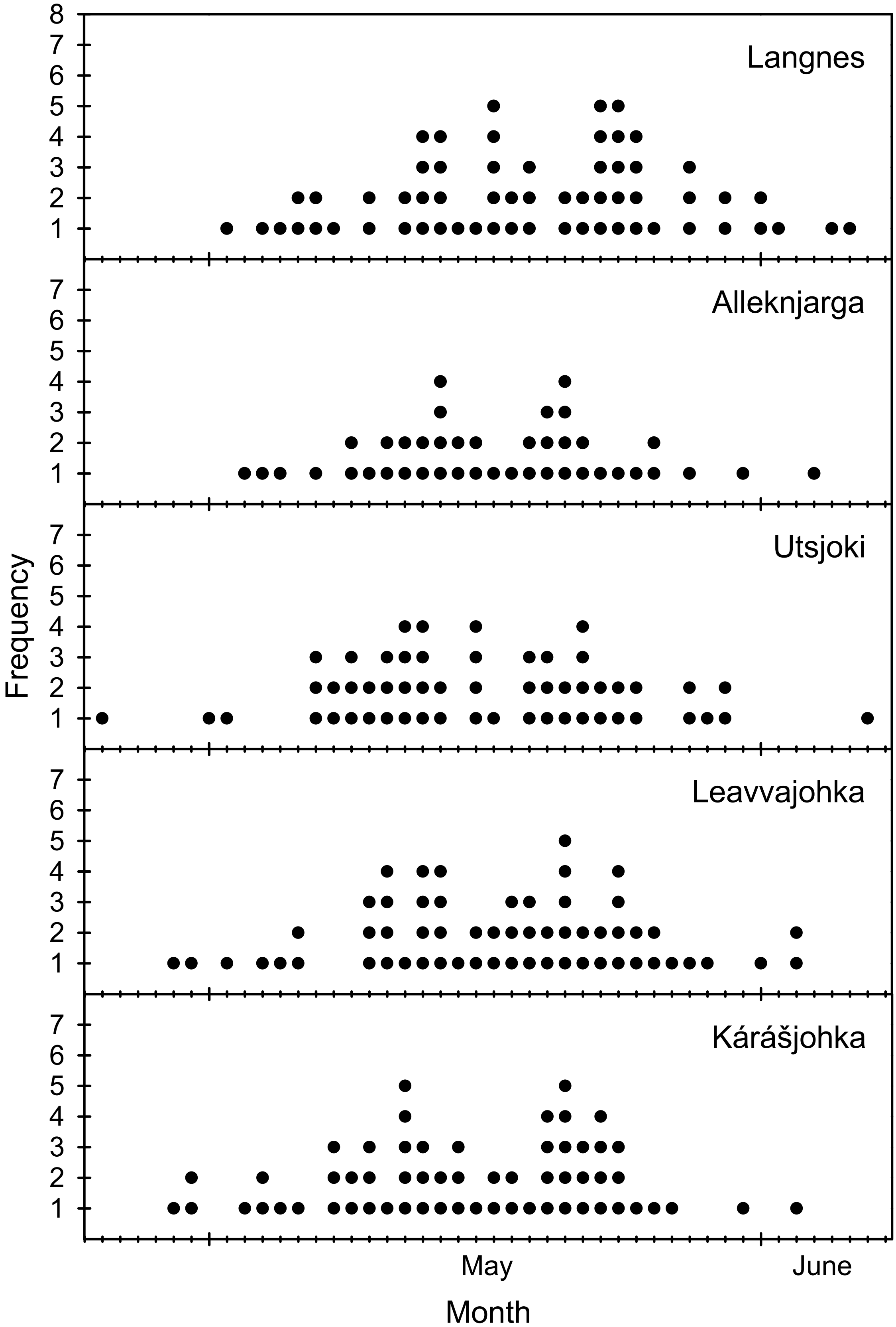
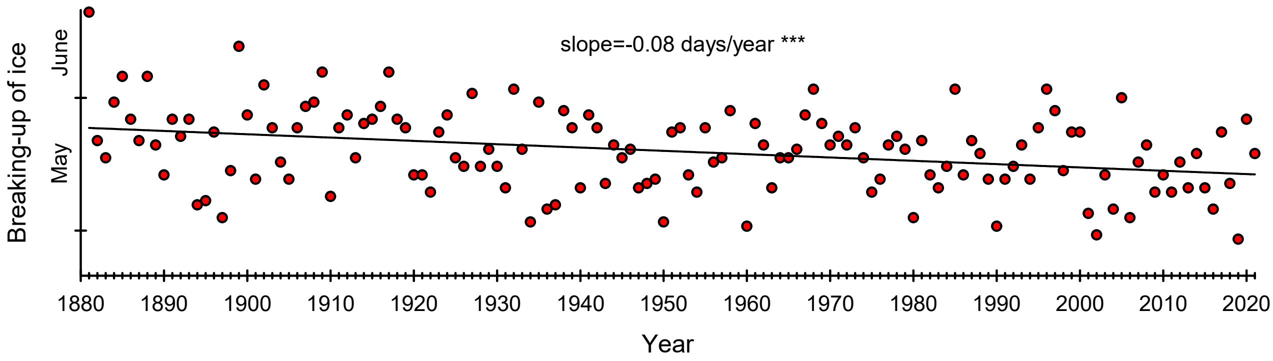


Figure 54. Ice break-up dates in the River Tana watershed. Source; NVE (Norway), Finnish Environment Institute, Edvard Nordsletta (personal information from Karasjohka), Kristian Sundelin (personal information from Langnes/Tana river mouth).



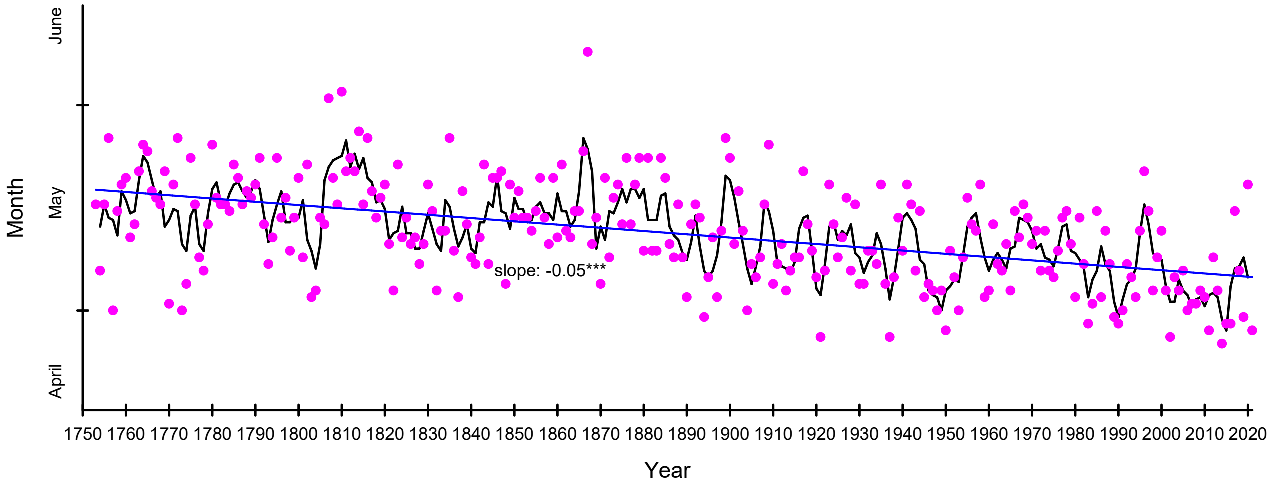


Figure 55. Ice breaking-up dates in the River Tana in Levajohka site (figure above) and in the River Tornio in West-Lapland (figure below). Regression lines indicates that ice breaking-up dates nowadays have taken place earlier than in the end of 1800s' in the River Tana and in the end of 1700's in the River Tornio. Source; NVE (Norway), Finnish Environment Institute.

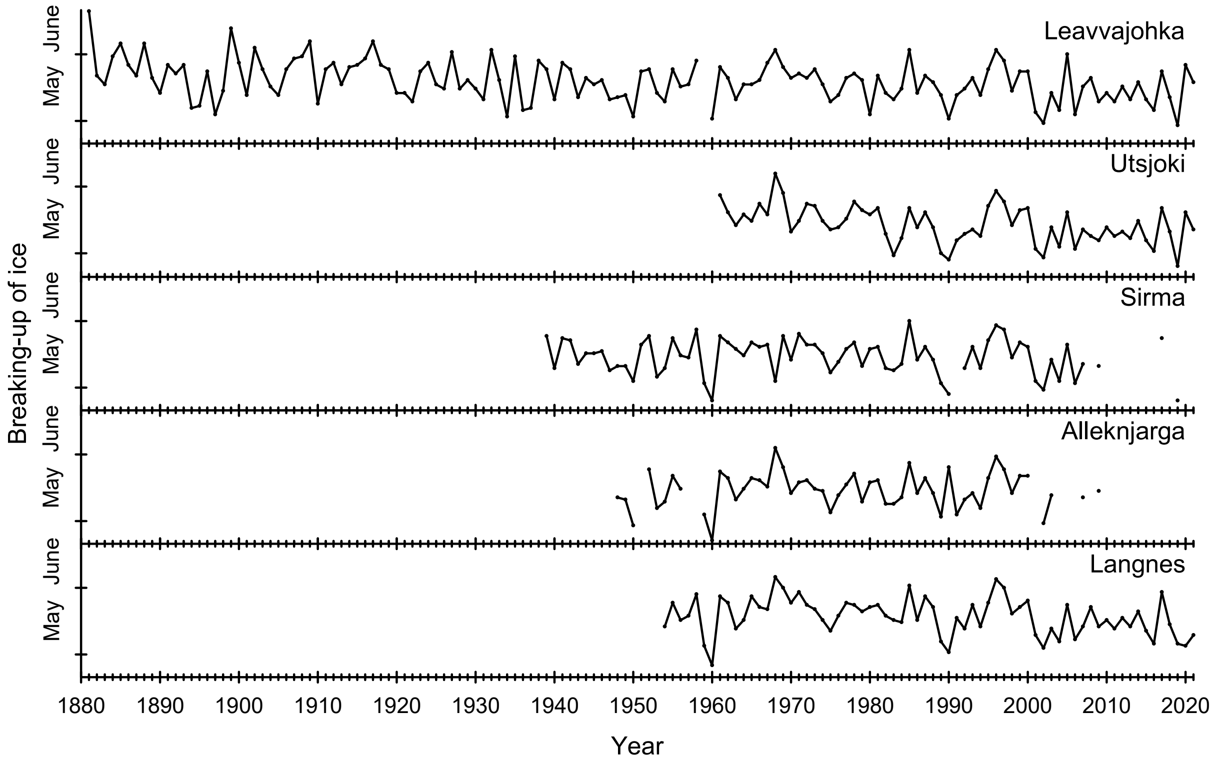


Figure 56. Historical ice breaking up dates in the River Tana watershed. Source; NVE (Norway), Finnish Environment Institute.

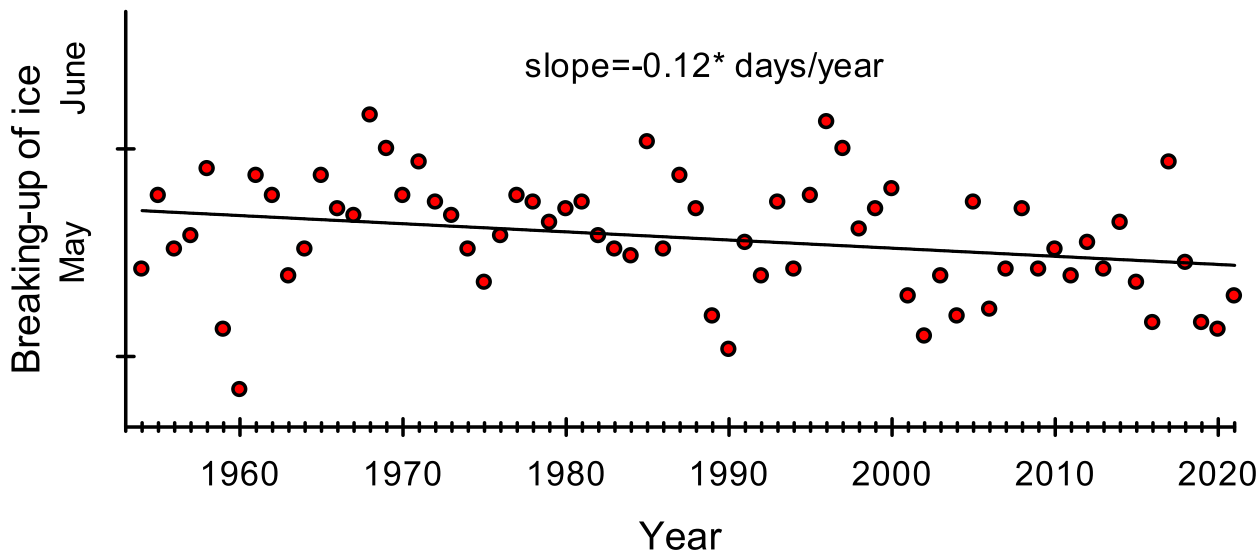


Figure 57. Ice breaking-up dates in the River Tana in Langnes (Tana River mouth). Regression line indicates that ice breaking-up dates have been taking place nowadays earlier than in the middle of 1950's. Source; NVE (Norway), Kristian Sundelin (personal information from Langnes/Tana rivermouth).

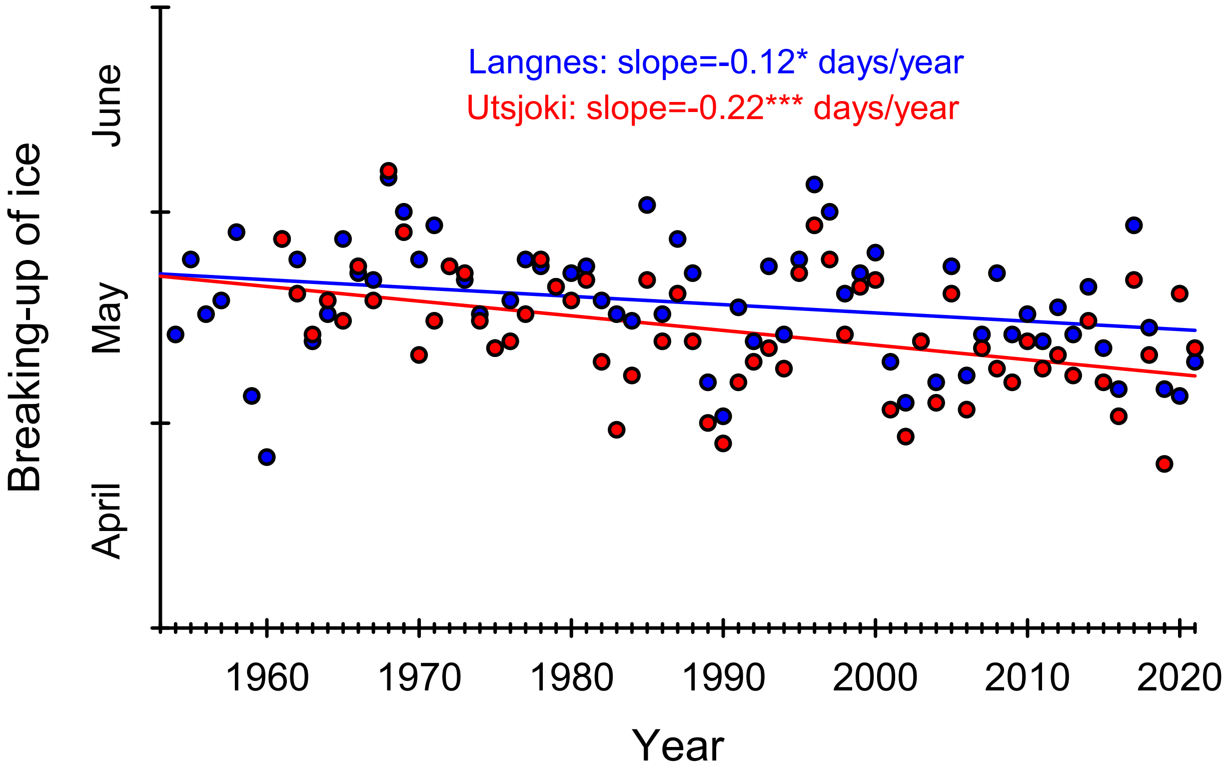


Figure 58. Ice breaking-up dates in the River Tana in Langnes (Tana river mouth) and in Utsjoki (Onnela) area. Regression lines are indicating that ice breaking-up dates are taken place nowadays earlier in both sites than earlier. Source; NVE (Norway), Finnish Environment Institute.

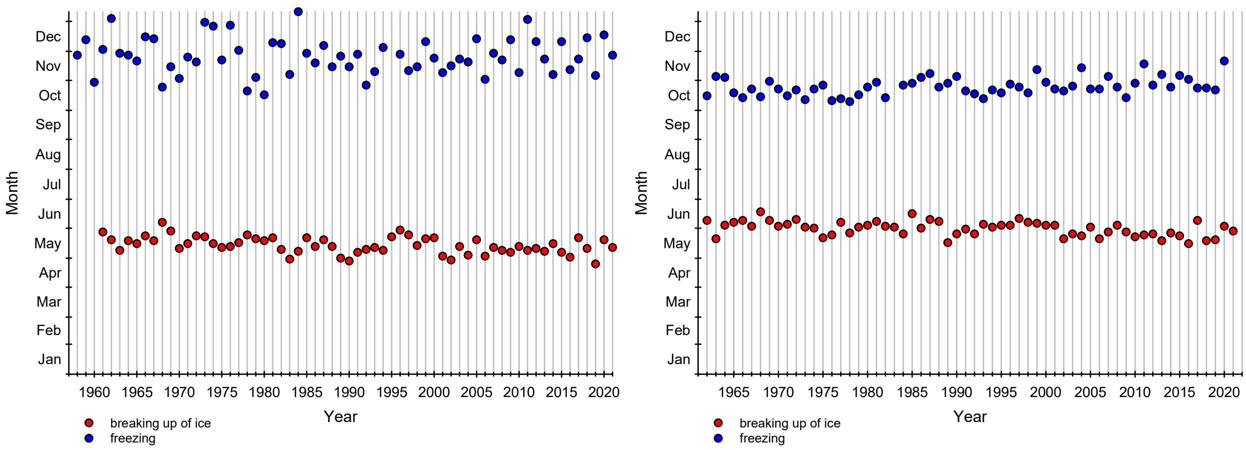


Figure 59. Water freezing periods in the River Tana (Onnela site, Utsjoki) are more variable compared to the ice breaking-up dates (figure to the left). Ice freezing takes place earlier in the lake Kevojärvi (in the tributary river Utsjoki) compared to ice freezing in the River Tana (figure to the right). Source; Finnish Environment Institute.

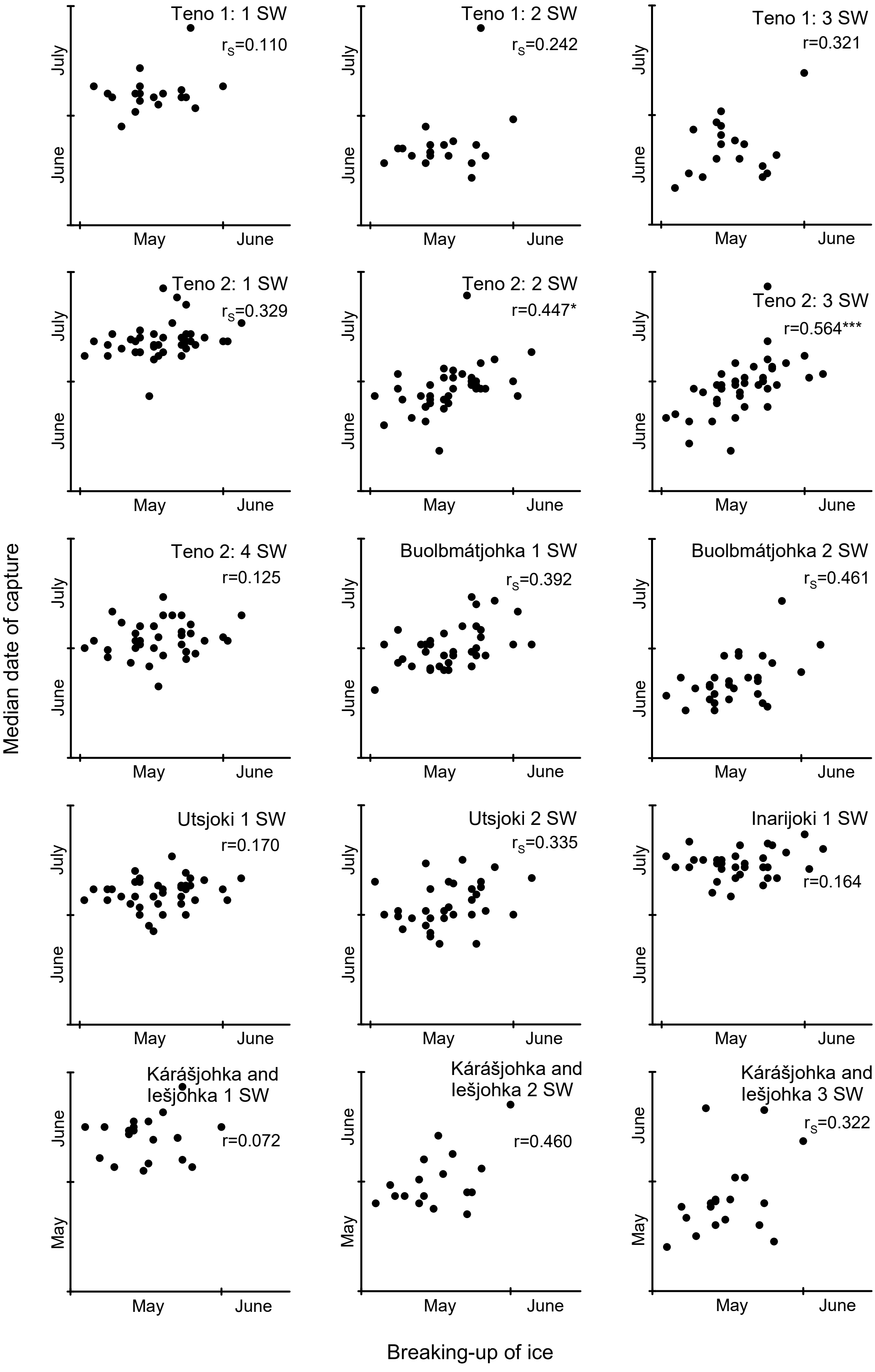


Figure 60. Relations between the ice breaking-up dates in Langnes (in the River Tana mouth) and median dates of salmon captures in different areas within the River Tana watershed. Source; NVE (Norway), Kristian Sundelin (personal information from Langnes/Tana River mouth), Luke (Utsjoki); TF organization (Norway).

The date of the ice break-up has had great impact to the median date of salmon capture and if the median date arrives earlier or later than normal. Especially the three sea-winter salmon (3SW) is affected, but slightly also the two sea-winter (2SW) salmon. The phenomenon is obvious in the River Tana area where we have precise daily catch data from salmon scale material in the Norwegian Finnish common border area. Large three sea winter salmon is normally ascending at earliest, late in the spring and early in summer, into the River Tana. Therefore, the ascend period of this large salmon into the River Tana is responding into the ice break-up dates; late ice break-up results in a late run. Smaller salmon, like one sea winter salmon (1SW) ascends into the River Tana mainly very late in June and the whole July month and ice melting period doesn´t determine their migration period. If ice break- up dates continue to take place earlier and earlier in the coming years due to global temperature changes it might reflect to the earlier ascend of 3SW salmon. An earlier ascend of the 3SW salmon means that they will be exploited in the river fishery for a longer period compared to years with late ice-break up.