Vulnerability assessment of ecosystem services for climate change impacts and adaptation (VACCIA)

Action 10: Assessment of impacts and adaptation of fisheries production and wash off effects in Lake Päijänne

April 30 2010

Report 2

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1. Introduction

Lake Päijänne is one of the three lakes having a surface area larger than 1000 km^2 in Finland. It is also the deepest lake in Finland, maximum depth is 94 m. The lake water level was artificially lowered in 1832-1837 and it has been regulated since 1964 (Järvinen and Marttunen 1998). Currently it is recovering from pulp and paper mill wastewater loading. Lake water is used for source of tap water in Helsinki metropolitan area. Lake Päijänne is one site in the Finnish Long Term Socio-Ecological Research Network.

In report 1 the present situation of fish stocks and fisheries in L. Päijänne as well as lake and drainage area characteristics were described. In this paper, report 2, the preliminary results of the climate change impacts are presented.

At first, the aim was to model the possible and expected changes in lake hydrology and water quality and their sensitivity to human activities on drainage area. The focus was to model ice cover duration and lake water temperature distribution in future climate. Also possible changes in dissolved oxygen in L. Päijänne are evaluated. Second, the effect of estimated changes to fish stocks was evaluated. Focus was on vendace stocks because vendace is economically the most important species. The predicted temperatures were used in biological models. The aim was to analyze the reproduction and growth of vendace in predicted temperatures.

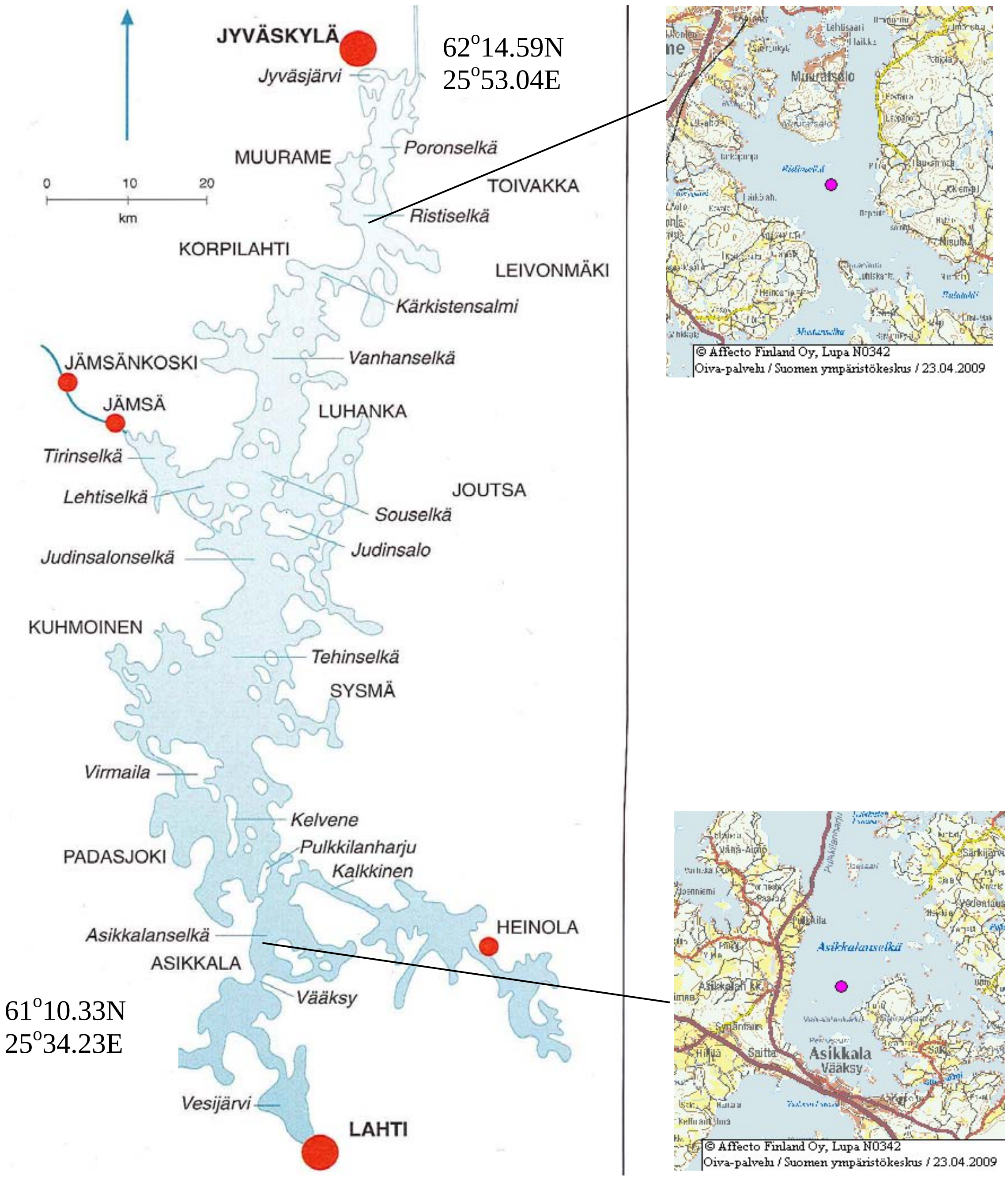


Figure 1. Map of Lake Päijänne. Right panel: maps showing the selected areas in L. Päijänne for temperature and water quality modeling, Asikkalanselkä (in south) and Ristinselkä (in north). *Sources: Hakkari and Saukkonen 1998; FEI database.*

2 Lake thermodynamics and water quality modeling
2.1 Methods and data

Research sites

Lake Päijänne is oriented in North-South direction with a maximum length of 120 km and width of 28 km (Figure 1). Two basins were selected for modeling: Asikkalanselkä basin located in the southern part, and Ristinselkä basin in the northern part of the lake system (Figure 1, Table 1). Lake and drainage area characteristics are presented in detail in report 1.

Table 1. Characteristics of the selected basins in Lake Päijänne.

	Northern Päijänne	Southern Päijänne
Area, ha	14066	7667
Mean depth, m	16.2	13.1
Max. depth, m	94.5	79
Volume, million m^3	228. 3	100.4

MyLake-modeling

Changes in water temperature and ice cover in the basins of Asikkalanselkä (Southern Päijänne) and Ristinselkä (Northern Päijänne) were modeled with MyLake (Multi-year Lake simulation model) (Saloranta and Andersen 2007). MyLake model is developed at the Norwegian Institute for Water Research and was applied in e.g. BMW, THERMOS and EUROLIMPACS -projects (Saloranta 2006, Lydersen et al. 2003). The MyLake model code consists of five modules, and three input and parameter data files are required to run the application in MATLAB. Model input data include meteorological and lake discharge data in a daily basis.

As a preliminary test for model performance comparisons with observed and modeled temperature were made with the MyLake model (Figure 2 and 3). Winter and autumn observed and modeled temperatures were quite close each other. Some discrepancies occurred with the depth of stratification layer during summer. In this preliminary application no model calibrations were made, and most of the parameters (e.g. diffusion parameters and PAR attenuation coefficient) were the same as in FINESSI-project (http://www.finessi.info) except for lake characteristic values (e.g. latitude and longitude, model vertical grid step).

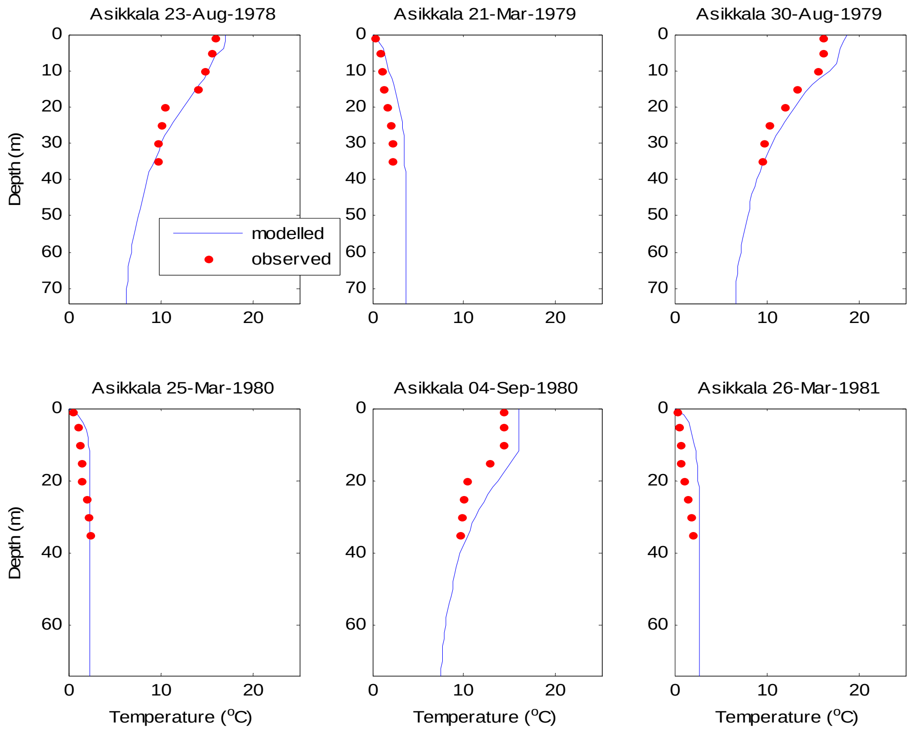


Figure 2. Comparison between modeled and observed lake water temperature in Asikkalanselkä basin in 1978-1981.

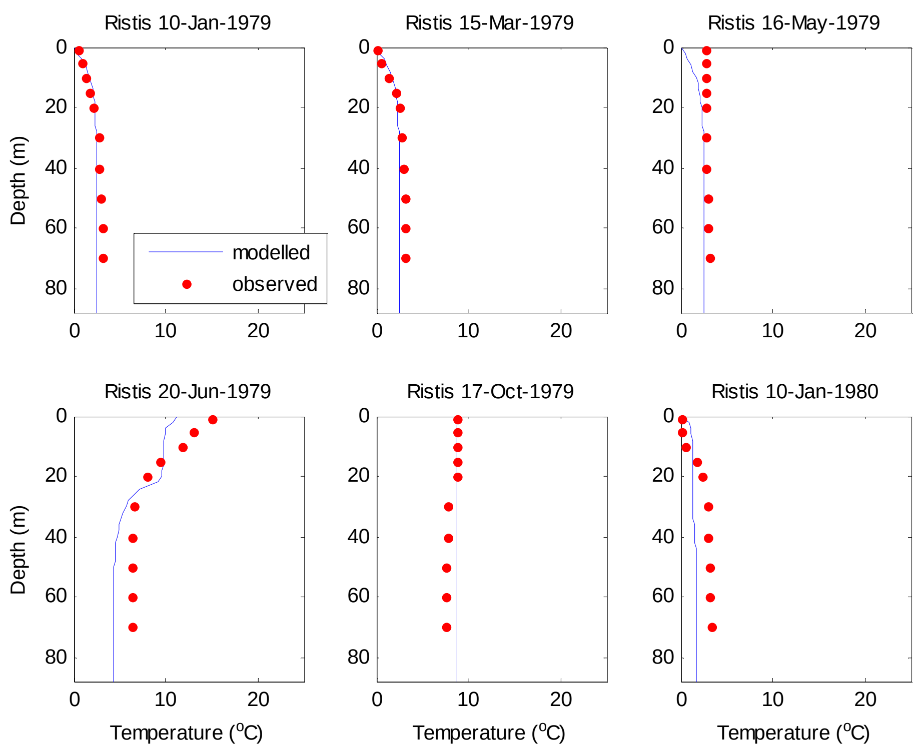


Figure 3. Comparison between modeled and observed lake water temperature in Ristinselkä basin in 1979-1980.

Meteorological and lake data

The Finnish Meteorological Institute (FMI) provided both the baseline observational data (period 1971-2000) and local climate chance scenario data (scenarios A2, A1B and B1; IPCC 2007) for 2010-2039, 2040-2069 and 2070-2099 for Asikkalanselkä (Lahti) and Ristinselkä (Jyväskylä). Meteorological input data for MyLake model were global radiation (MJm^{-2}), cloud cover, air temperature (^oC), relative humidity (%), air pressure (hPa), wind speed (ms^{-1}) and precipitation (mm) in daily basis. In scenario model runs relative humidity, air pressure and wind speed daily values were the same as in baseline data (1971-2000). Cloud cover for future time periods was estimated from the baseline cloud cover and baseline and future global radiation values. The scenario data grid resolution for mean temperature and precipitation was 0.25^o x 0.25^o and for global radiation 0.5^o x 0.5^o (Jylhä and Laapas 2009).

Inflow data and lake characteristic parameters for MyLake model were provided by Finnish Environment Institute (FEI) for later use in drainage area modeling. Lake water temperature data for comparison of modeled temperature was retrieved from the Hertta-database (FEI). Also dissolved oxygen data was retrieved from the Hertta-database (FEI).

Modeling of dissolved oxygen concentration

A linear regression between water temperature and dissolved oxygen concentration was made by plotting the measured and observed values of temperature and oxygen in March and in August. In Ristinselkä basin the regression functions were made with 57 observations for 10 depths (1, 5, 10, 15, 20, 30, 40, 50, 60 and 70 m) and in Asikkalanselkä the regression is based on 36 observations for 6 depths (1, 5, 10, 15, 20, 30 m).

2.2 Results

2.2.1 Ice cover in L. Päijänne

In current climate the ice cover in Tehinselkä, middle of L. Päijänne, forms on average in late December and melts in late April (Korhonen 2005). The ice-covered period has already been shortening because during the past decade the ice cover has formed in early January. According to MyLake modeling results regarding ice formation and ice-out under scenarios A1B and A2, in Asikkalanselkä basin the ice-covered period begins in middle of January and lasts to early March in 2070-2099 (Table 2.). In some years during that time period no ice cover will be formed at all and the occurrence of successive freezing and ice-out will be likely. Under scenario B1 the ice-covered period is the longest in this comparison, and with only few ice-out days after the initial day of freezing. In Northern Ristinselkä basin MyLake model produces similar results than in Asikkalanselkä basin with the scenarios, and the ice-covered period remains few days longer than in Southern Asikkalanselkä basin also in future.

Table 2.Modeled mean occurrence of ice in Asikkalanselkä and Ristinselkä basins during 1971-2000 (baseline) and 2070-2099 according to scenarios A1B, A2 and B1.

		Ice cover formation	Ice cover melting
Asikkalanselkä basin	1971-2000	7.12.	15.5.
	A1B	10.1.	4.3.
	A2	17.1.[a)]	8.3.
	B1	5.1.	29.3.
Ristinselkä basin	1971-2000	1.12.	18.5.
	A1B	5.1.	25.3.
	A2	8.1.[a)]	16.3.
	B1	25.12.	27.3.

[a)] With several ice-out phases and years without no ice-cover.

2.2.2 Asikkalanselkä basin

Modeled surface water temperature

Modeled mean surface water temperature in Asikkalanselkä basin remained below 21 ^{o}C during the baseline 1971-2000 (Figure 4). According to all scenarios, the surface water temperatures tend to rise towards the end of the ongoing century (Figures 5-7) and the ice-covered period seems to be shortening with delayed ice formation. The temperature rise is more pronounced with scenario A2.

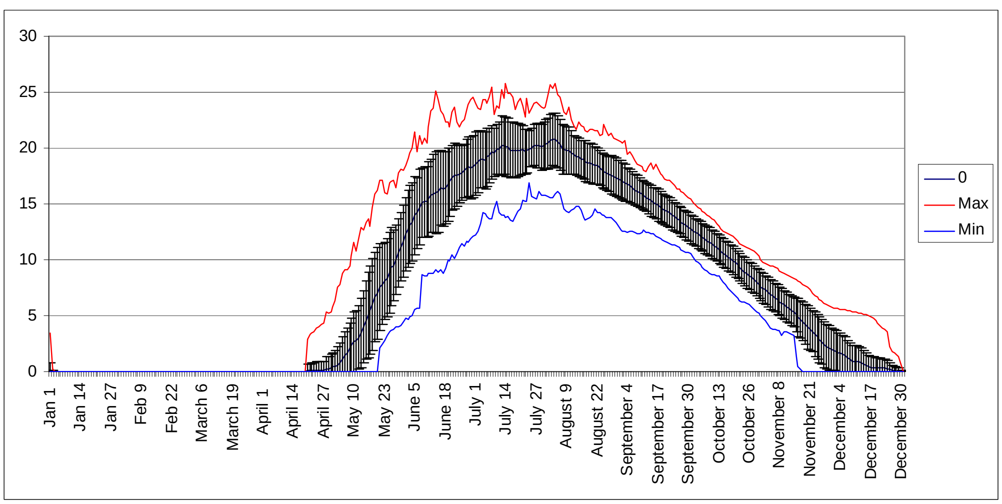
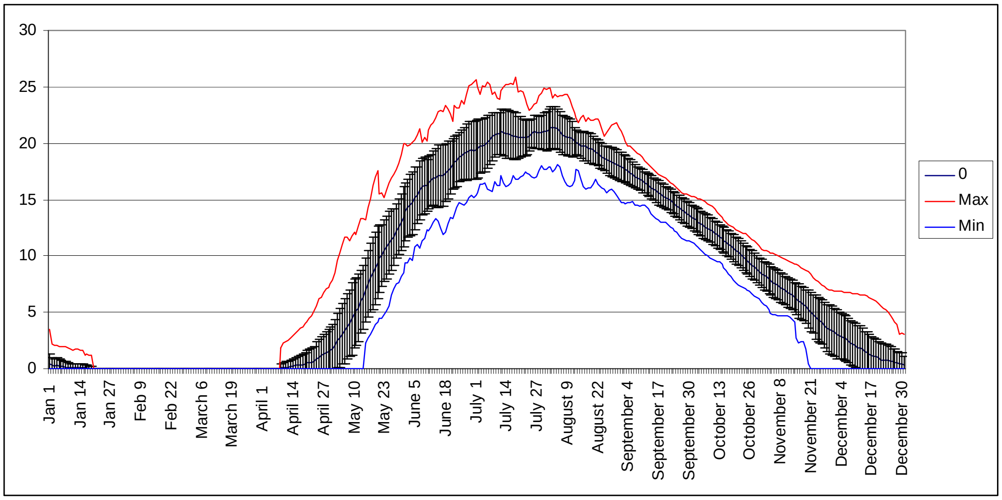
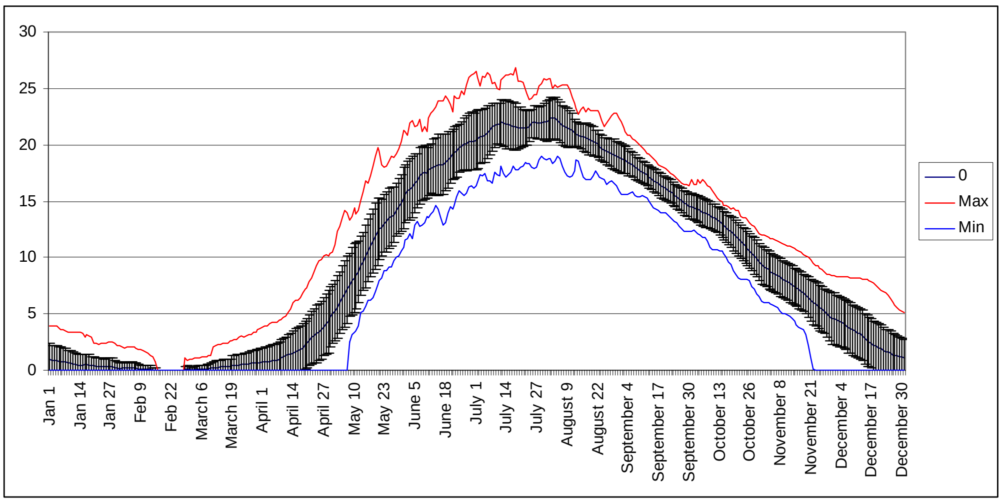


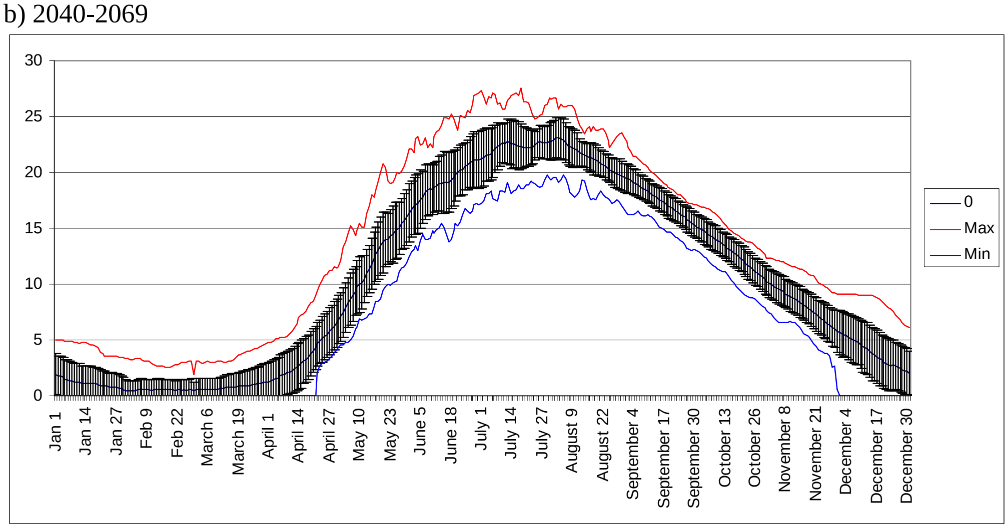
Figure 4. Modeled yearly distribution of surface water temperature (0 m) in Asikkalanselkä basin for the baseline 1971-2000. Average, maximum and minimum temperatures and standard deviation are calculated from 30 year´s daily data.



a) 2010-2039

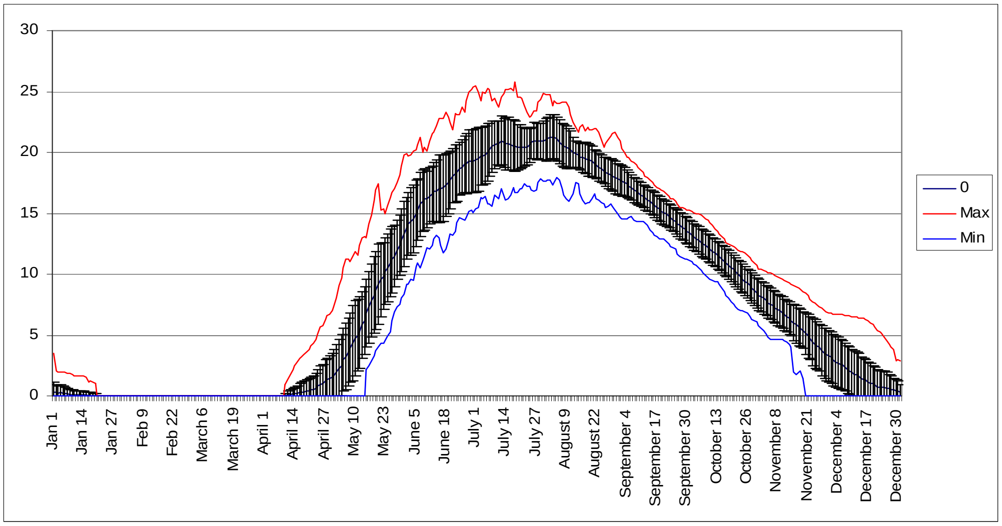


b) 2040-2069

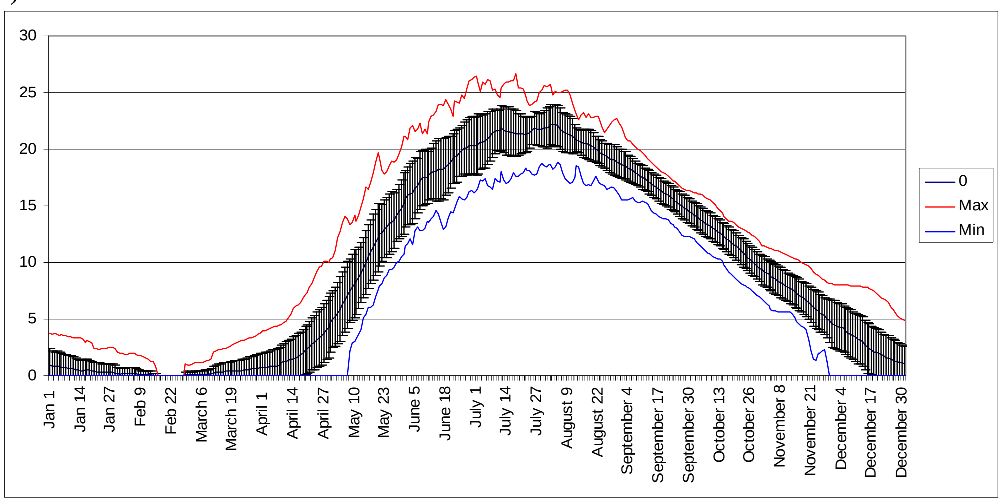


c) 2070-2099

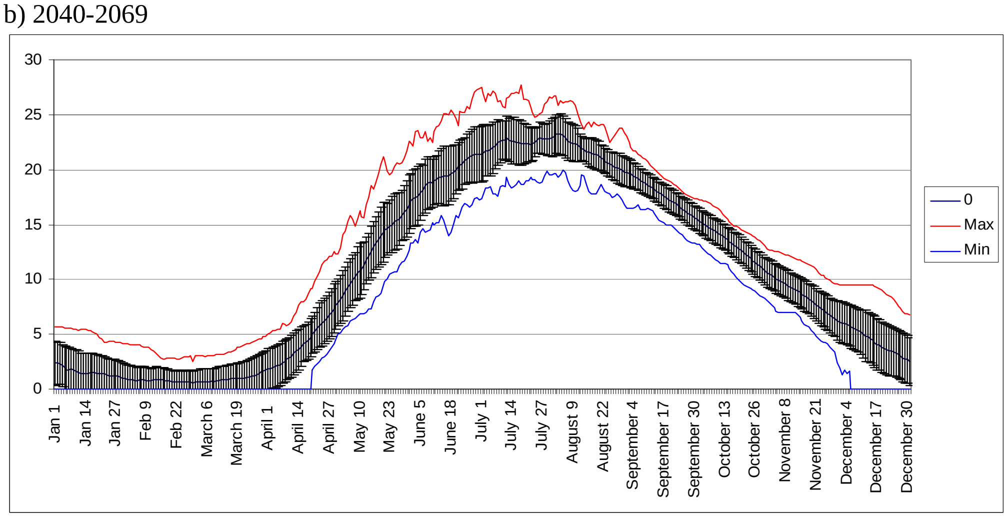
Figure 5. Modelled yearly distribution of surface water temperature (0 m) in Asikkalanselkä basin for the scenario A1B (a-c). Average, maximum and minimum temperatures and standard deviation are calculated from 30 year´s daily data (a, b, and c).



a) 2010-2039

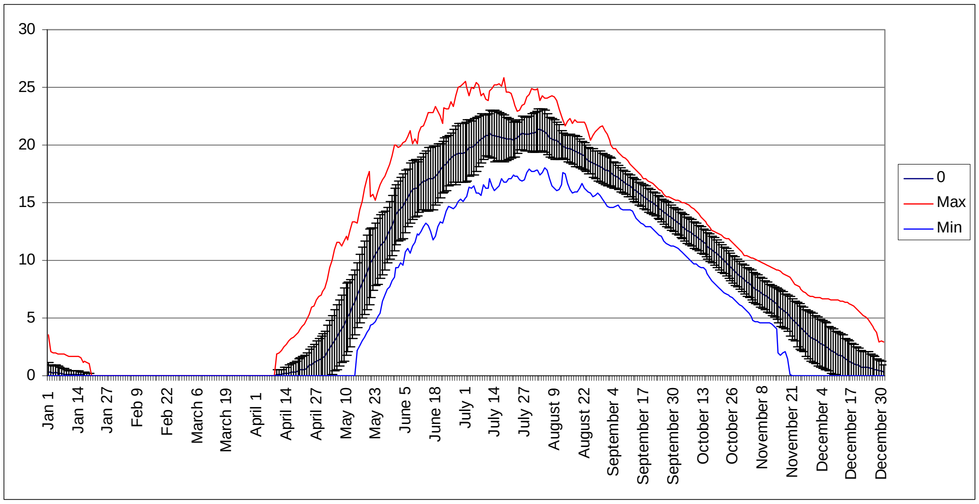


b) 2040-2069

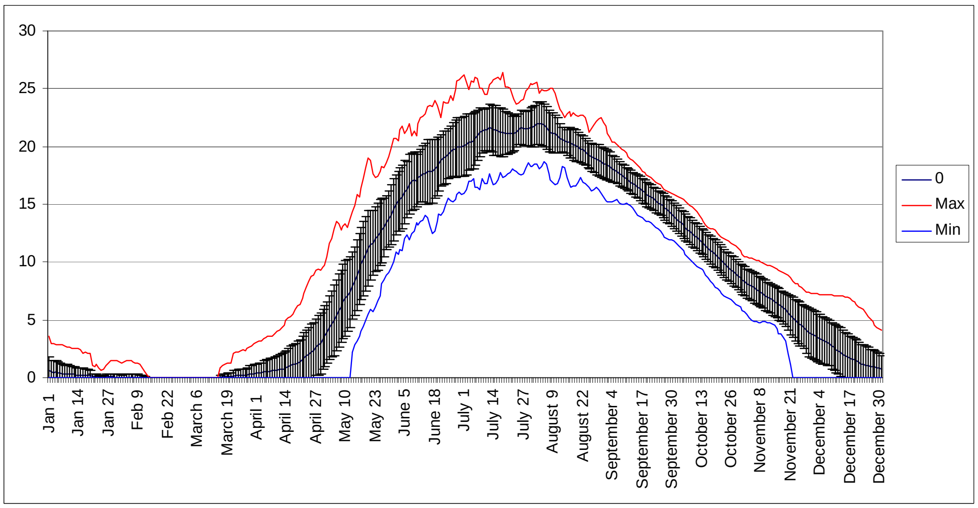


c) 2070-2099

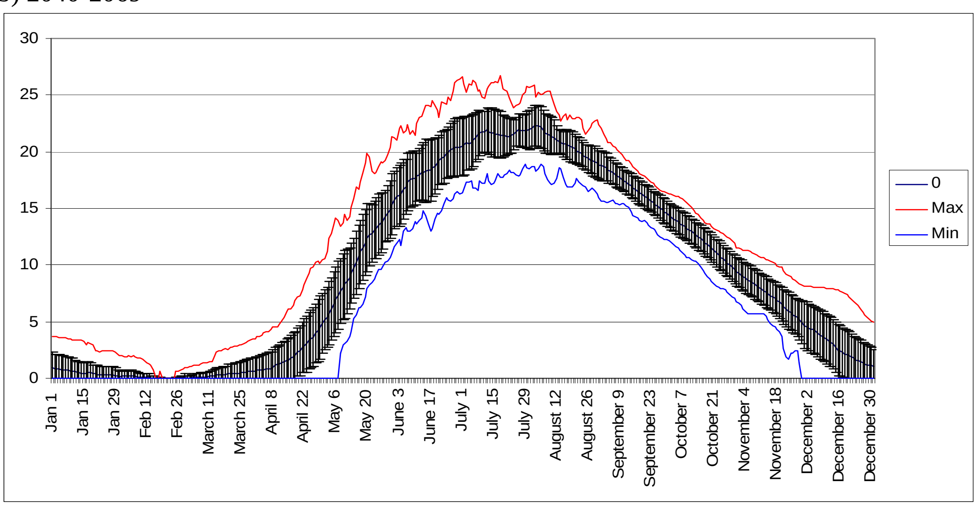
Figure 6. Modeled yearly distribution of surface water temperature (0 m) in Asikkalanselkä basin for the scenario A2. Average, maximum and minimum temperatures and standard deviation are calculated from 30 year´s daily data (a, b and c).



a) 2010-2039



b) 2040-2069



c) 2070-2099

Figure 7. Modeled yearly distribution of surface water temperature (0 m) in Asikkalanselkä basin for the scenario B1. Average, maximum and minimum temperatures and standard deviation are calculated from 30 year's daily data (a, b and c).

Modeled vertical distribution of temperature in March 1

Modeled mean vertical distribution of water temperature in March shows typical winter-time inverse stratification during the baseline 1971-2000 (Figure 8). According to scenarios A1B and A2, the water temperature in surface part (0-5 m) tend to rise (no ice formation) and possibly due to excess mixing water will be more cooler in bottom of the water column (Figure 9a, 9b). According to scenario B1 the vertical temperature in March does not differ from the current state except for slightly cooler water in the bottom parts of the water column (figure 9c).

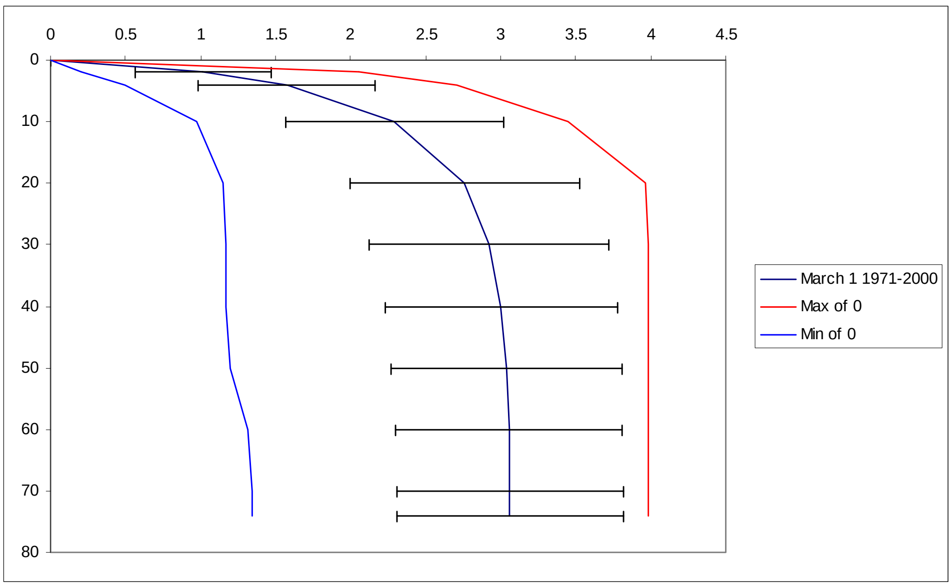
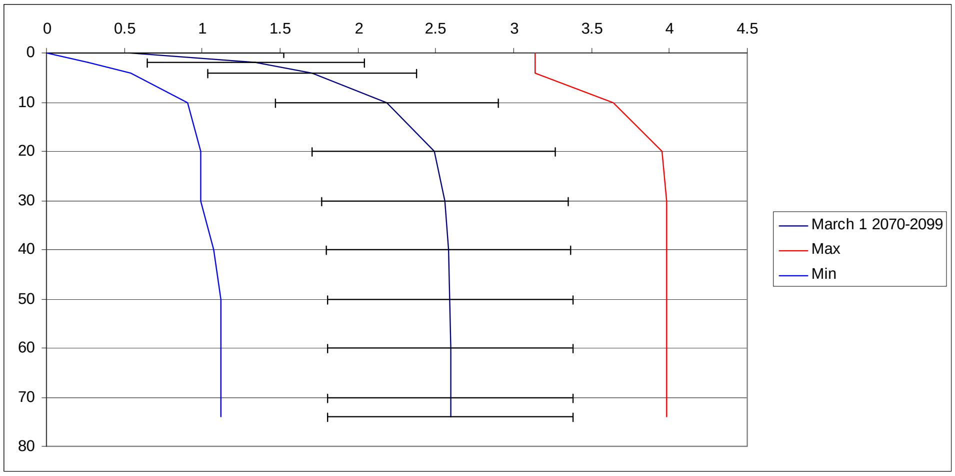
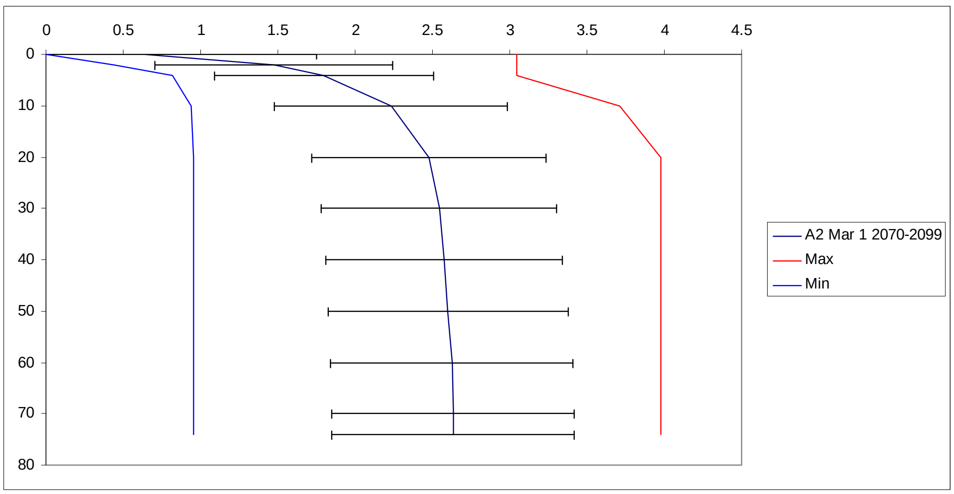


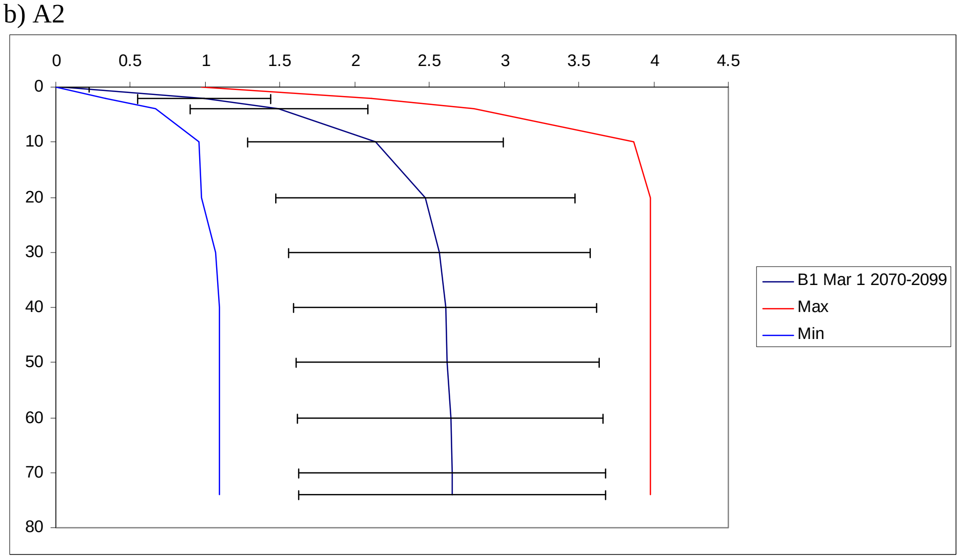
Figure 8. Modeled vertical distribution of water temperature in March 1st in Asikkalanselkä basin for baseline 1971-2000. Average, maximum and minimum temperatures and standard deviation are calculated from daily data.



a) A1B



b) A2

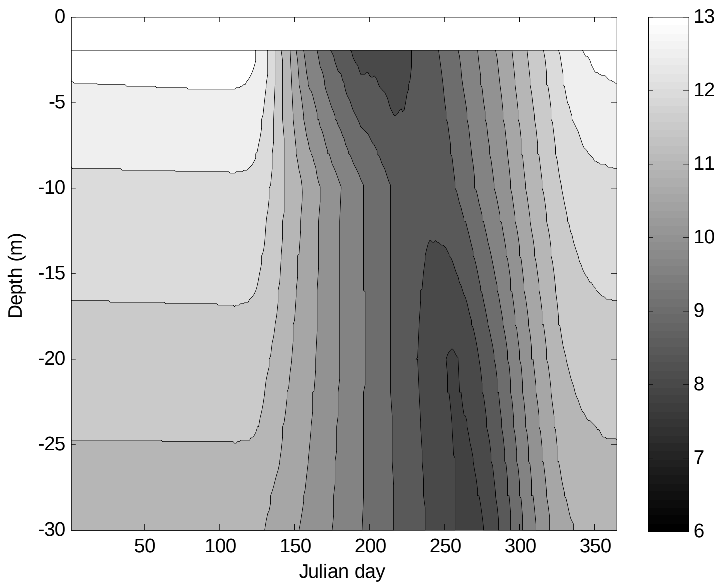


c) B1

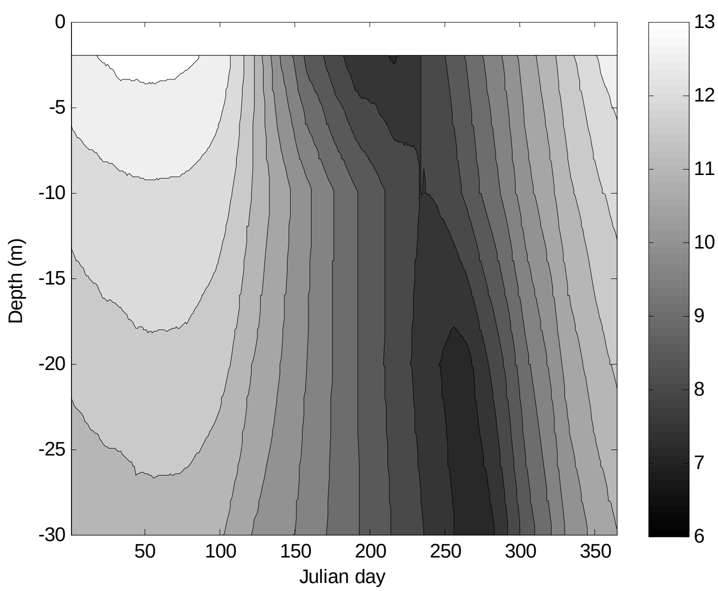
Figure 9. Modeled vertical distribution of water temperature in March 1st in Asikkalanselkä basin for 2070-2099. Average, maximum and minimum temperatures are calculated for different scenarios: a) A1B , b) A2 and c) B1 from 30 year´s daily data.

Modeled dissolved oxygen

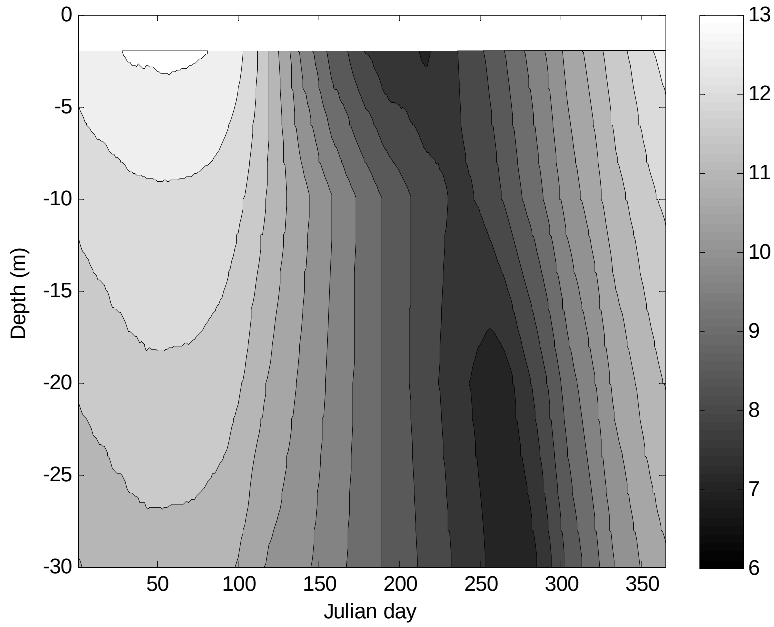
Modeled dissolved oxygen concentration showed clear stratification during winter and summer during the baseline (Figure 10 a.). In scenario runs towards the end of the 21st century (Figure 10 b-d) there were minimum concentrations also during winter, and with scenario A2 the oxygen concentration decreased to 7 mgl^{-1} both in surface and bottom parts of the water column (Figure 10 c.) .



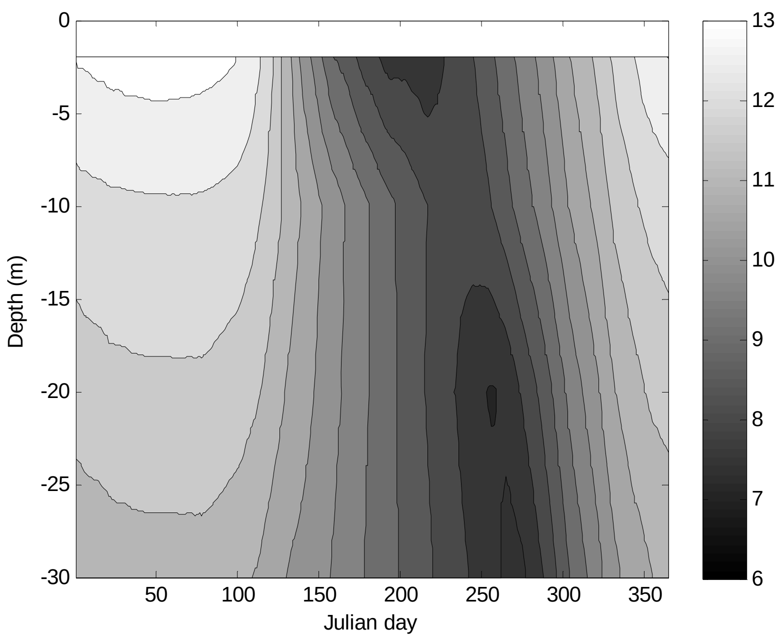
a) 1971-2000



b) A1B 2070-2099



c) A2 2070-2099



d) B1 2070-2099

Figure 10. Dissolved oxygen concentration (mgl^{-1}) isopleths in Asikkalanselkä basin, based on linear model a) during baseline (1971-2000) and b-d) according to scenarios A2, A1B and B1 in 2070-2099.

2.2.3 Ristinselkä basin

Meteorological observations and A1B scenario data

According to scenario A1B mean air temperature shows slight increase in each 30 year´s time step in Jyväskylä (Figure 11.). The change is more pronounced during winter. Mean global radiation is increasing during summer, but decreasing during winter and spring Figure 12.). No clear changes in mean precipitation are observable in any of the 30 year´s time series according to scenario A1B (Figure 13.).

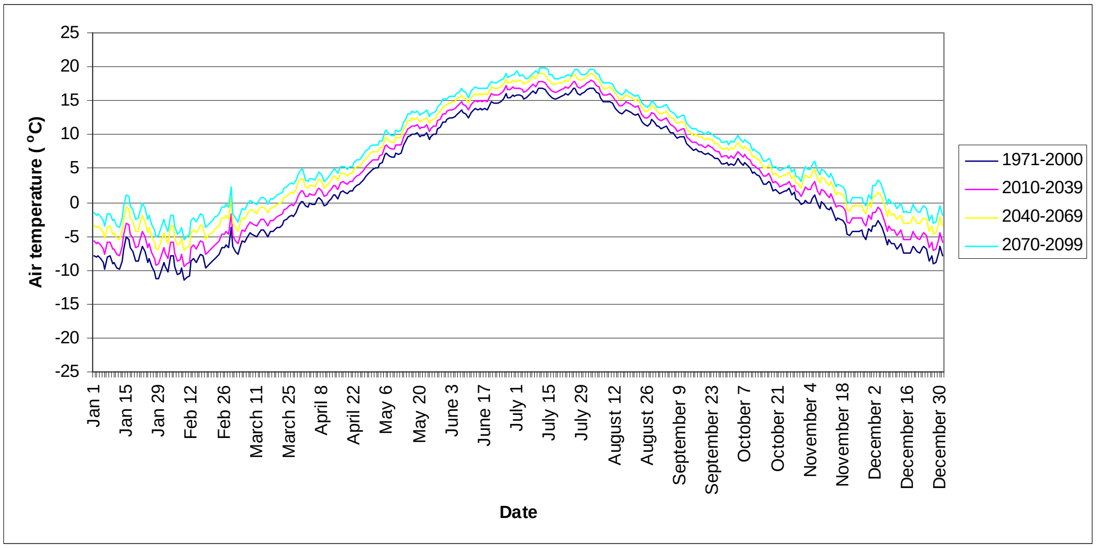


Figure 11. Mean air temperature (^{o}C) in Jyväskylä during baseline (1971-2000) and according to scenario A1B in 2010-2039, 2040-2069 and 2070-2099. Mean temperature is calculated from 30 year’s daily data

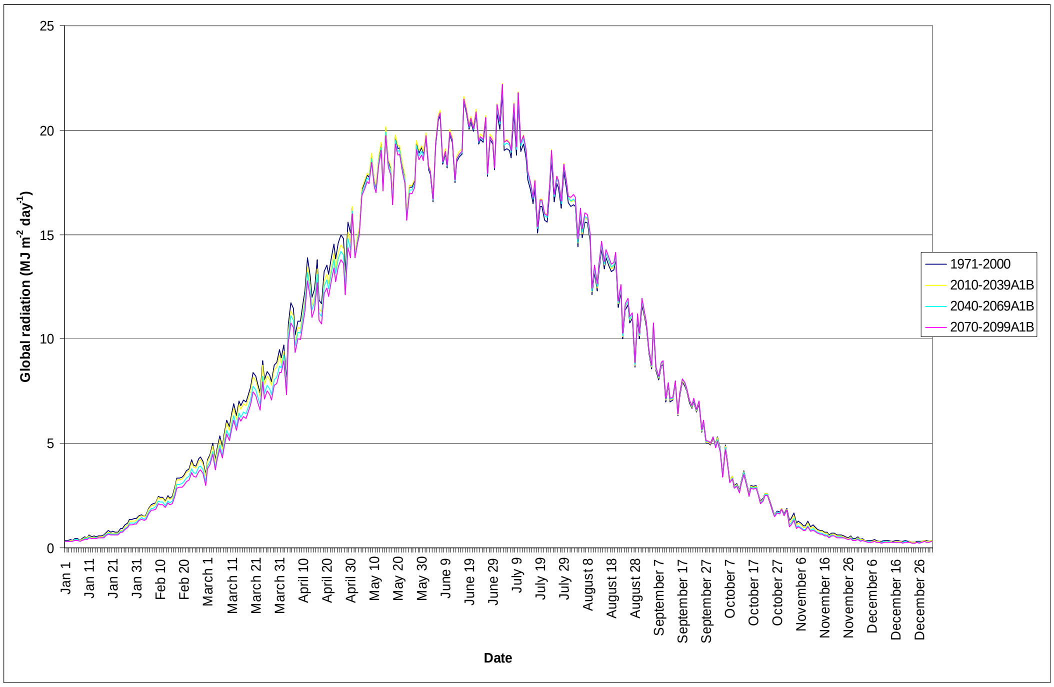


Figure 12. Mean global radiation (MJm^{-2}) in Jyväskylä during baseline (1971-2000) and according to scenario A1B in 2010-2039, 2040-2069 and 2070-2099. Mean global radiation is calculated from 30 year's daily data.

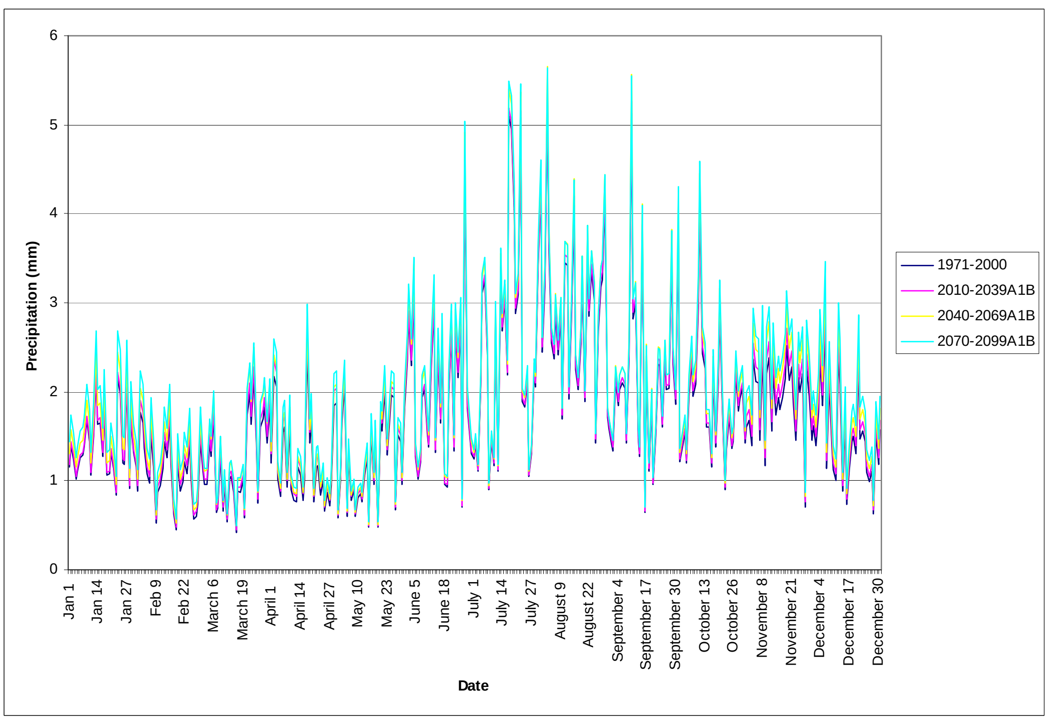


Figure 13. Mean precipitation (mm) in Jyväskylä during baseline (1971-2000) and according to scenario A1B in 2010-2039, 2040-2069 and 2070-2099. Mean precipitation is calculated from 30 year's daily data.

Modeled surface water temperature

Mean surface water temperature in Ristinselkä basin is lower than in Asikkalanselkä; it remained well below 20 °C during the baseline (1971-2000) modeling (Figure 14). According to all scenarios, the surface water temperatures tend to rise towards the end of the ongoing century (Figures 15-17) and the ice-covered period seems to be shortening with delayed ice formation. The temperature rise is more pronounced with scenario A2, as in Asikkalanselkä.

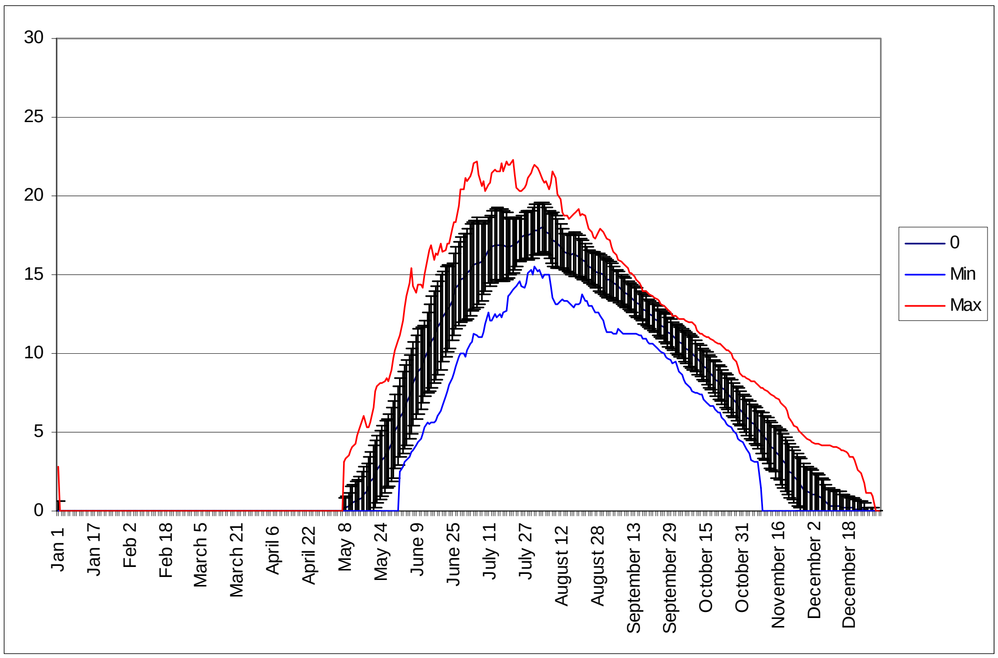
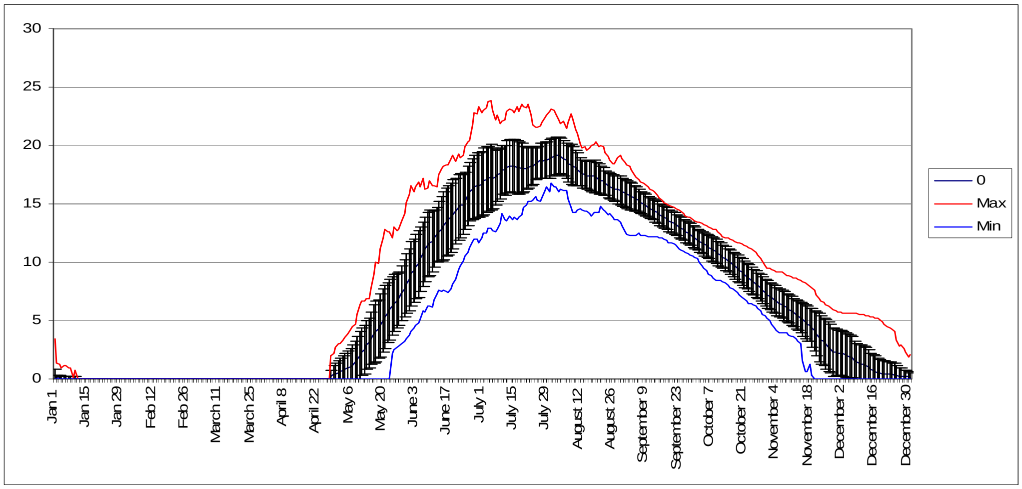
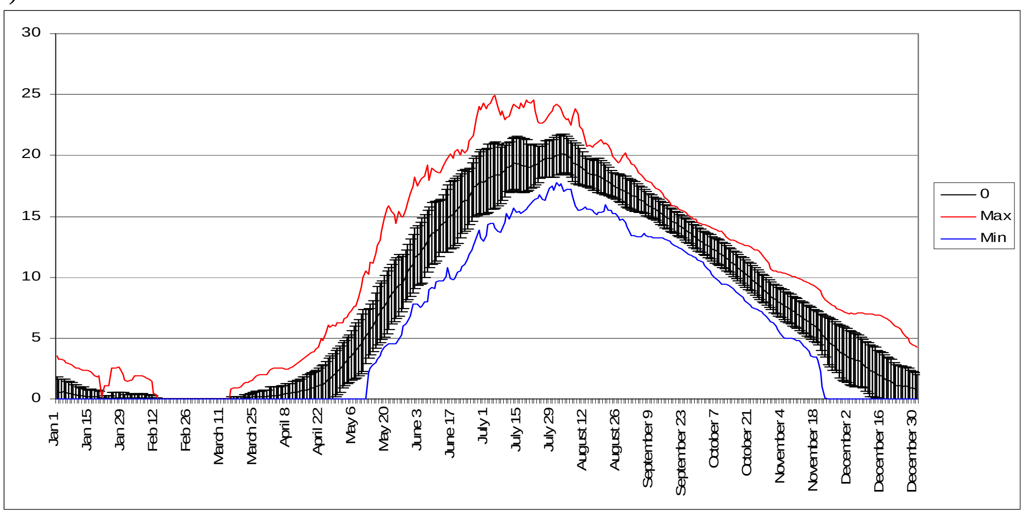


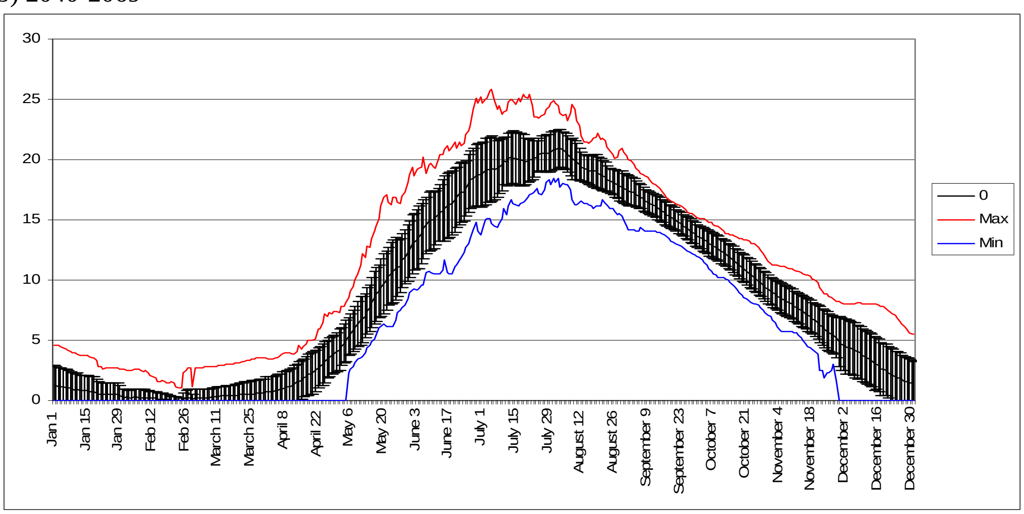
Figure 14. Modeled yearly distribution of surface water temperature (0 m) in Ristinselkä basin for the baseline 1971-2000. Average, maximum and minimum temperatures and standard deviation are calculated from 30 year´s data set.



a) 2010-2039

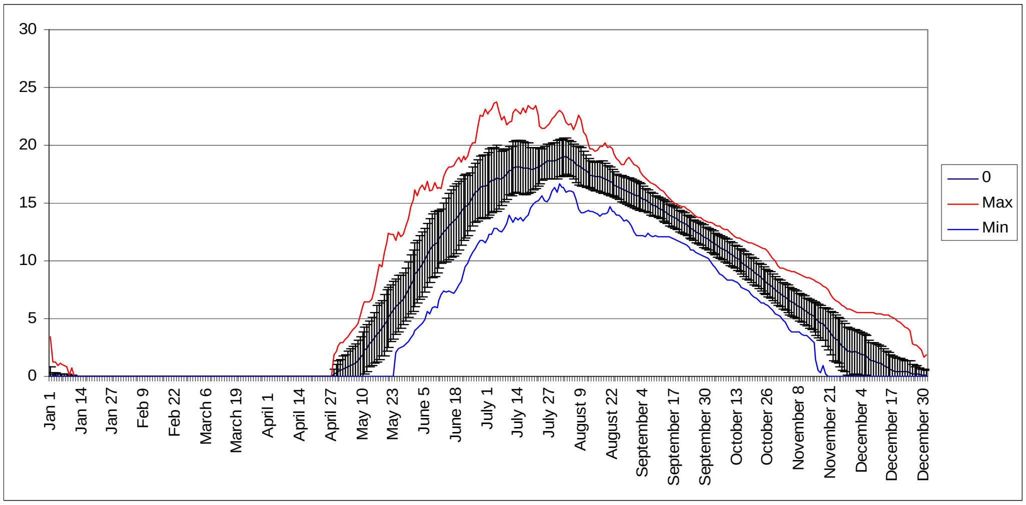


b) 2040-2069

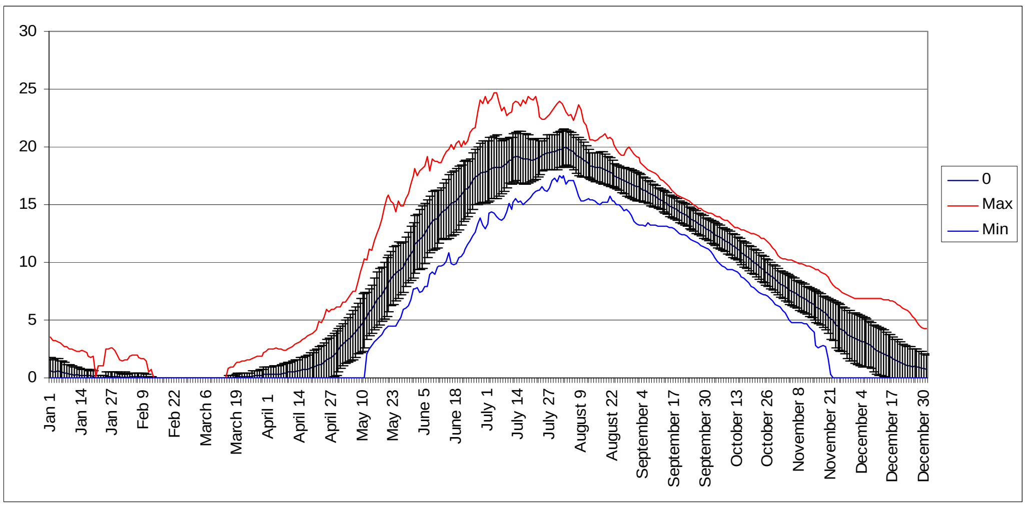


c) 2070-2099

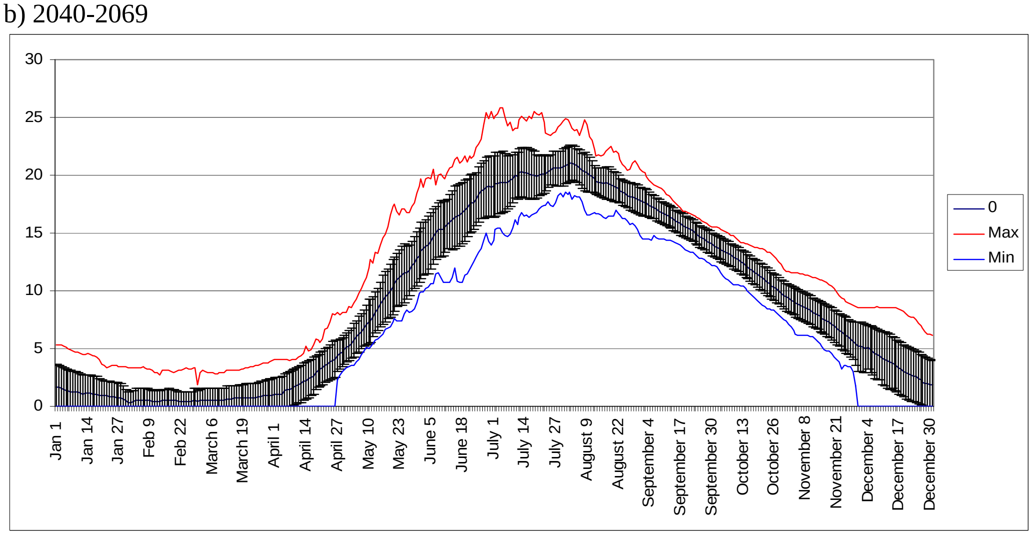
Figure 15. Modeled yearly distribution of surface water temperature (0 m) in Ristinselkä basin for the scenario A1B. Average, maximum and minimum temperatures and standard deviation are calculated from 30 year´s data set (a, b and c).



a) 2010-2039

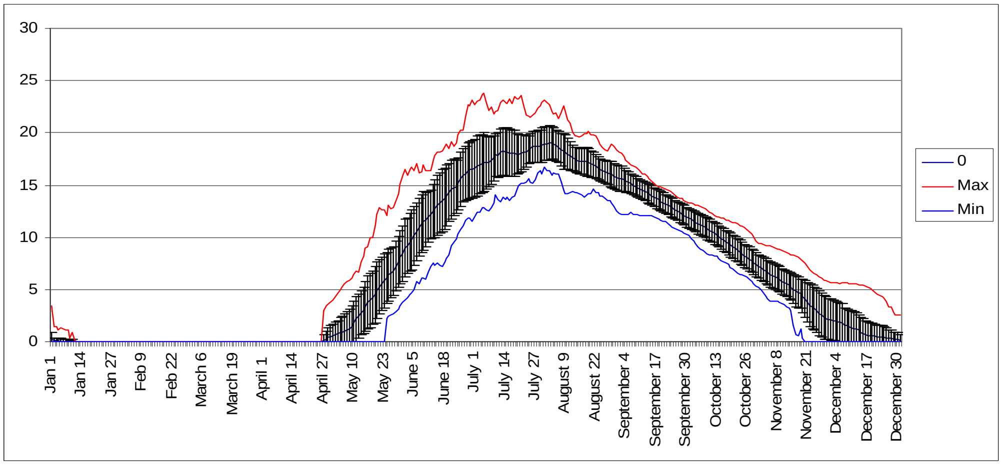


b) 2040-2069

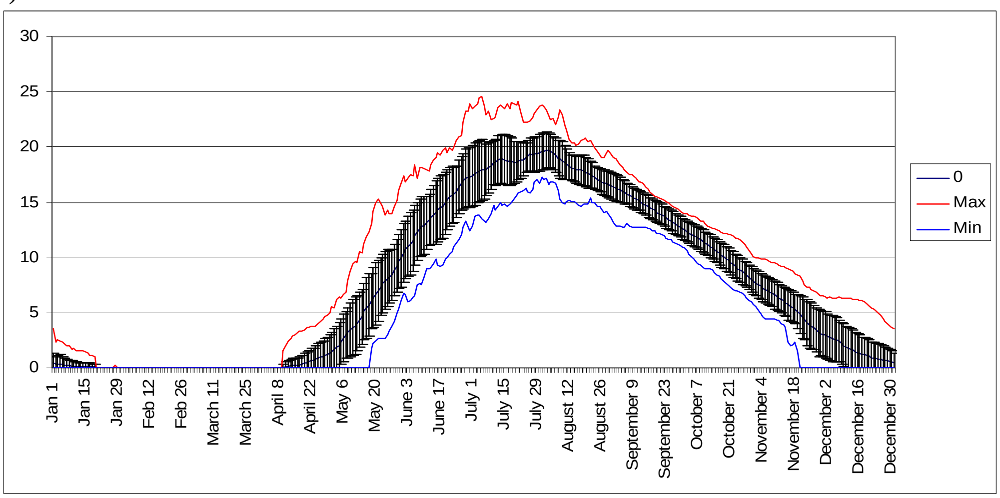


c) 2070-2099

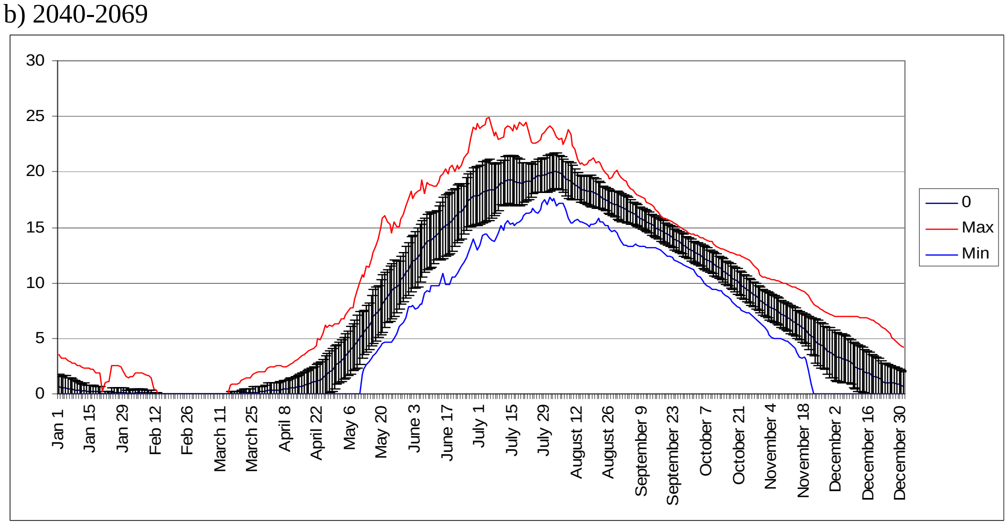
Figure 16. Modeled yearly distribution of surface water temperature (0 m) in Ristinselkä basin for the scenario A2. Average, maximum and minimum temperatures and standard deviation are calculated from 30 year´s data set (a, b and c).



a) 2010-2039



b) 2040-2069



c) 2070-2099

Figure 17. Modelled yearly distribution of surface water temperature (0 m) in Ristonselkä basin for the scenario B1. Average, maximum and minimum temperatures and standard deviation are calculated from 30 year´s data set (a, b and c).

Vertical distribution of temperature in March 1

Modeled mean vertical distribution of water temperature in March shows typical winter-time inverse stratification during the baseline 1971-2000 also in Ristinselkä (Figure 18). According to scenarios A1B and A2, the water temperature in surface part (0-5 m) tend to rise (no ice formation) and possibly due to excess mixing water will be more cooler in bottom of the water column (Figure 19a, b). According to scenario B1 the vertical temperature in March does not differ from the current state in Ristinselkä basin (figure 19c).

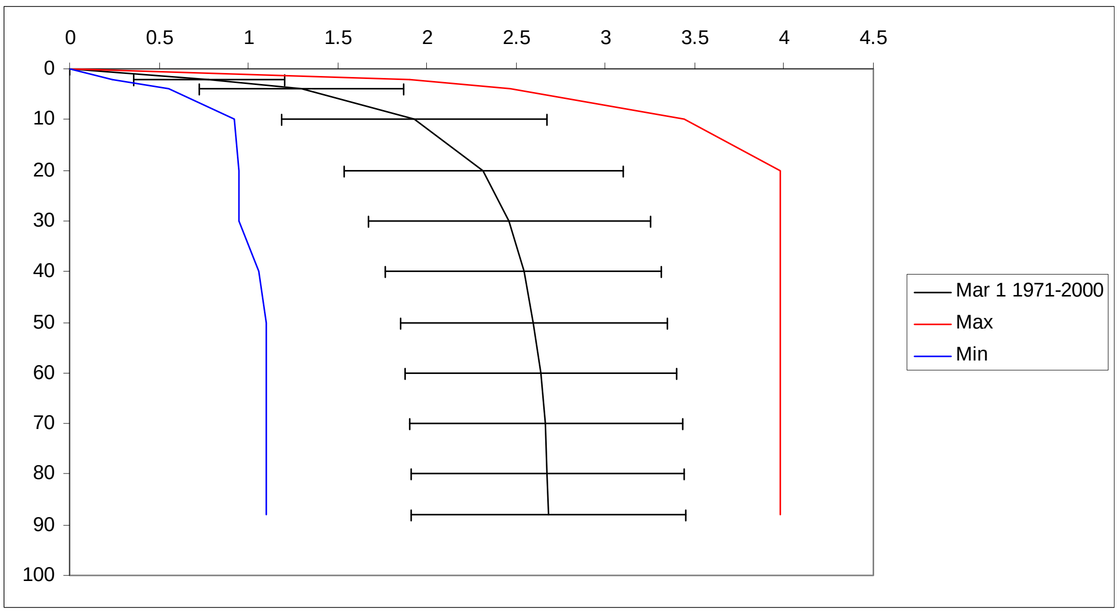
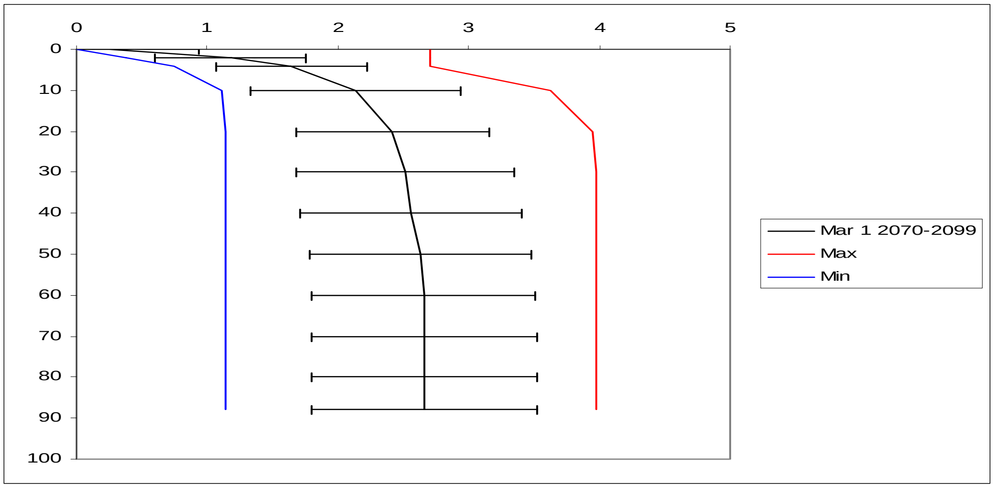
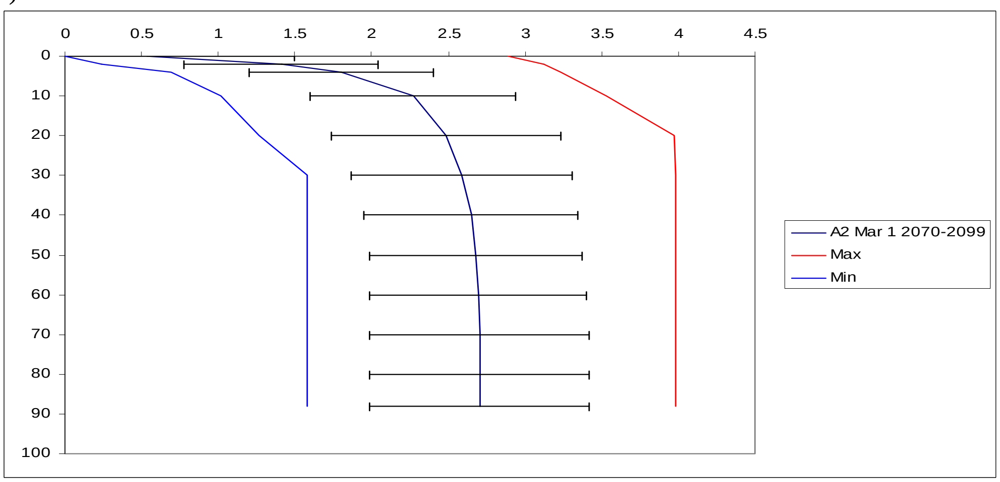


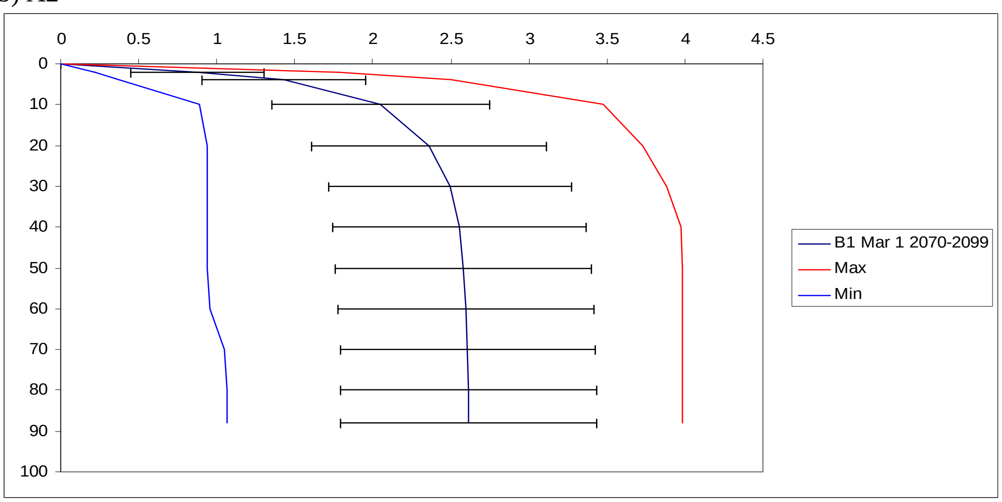
Figure 18. Modelled vertical distribution of water temperature in March 1st in Ristinselkä basin for baseline (1970-2000). Average, maximum and minimum temperatures and standard deviation are calculated from 30 year´s data set.



a) A1B



b) A2

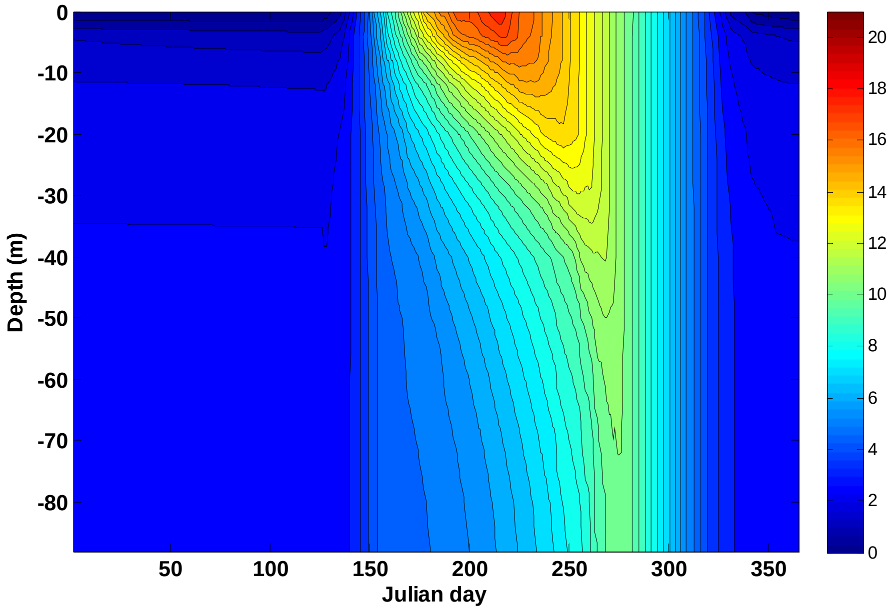


c) B1

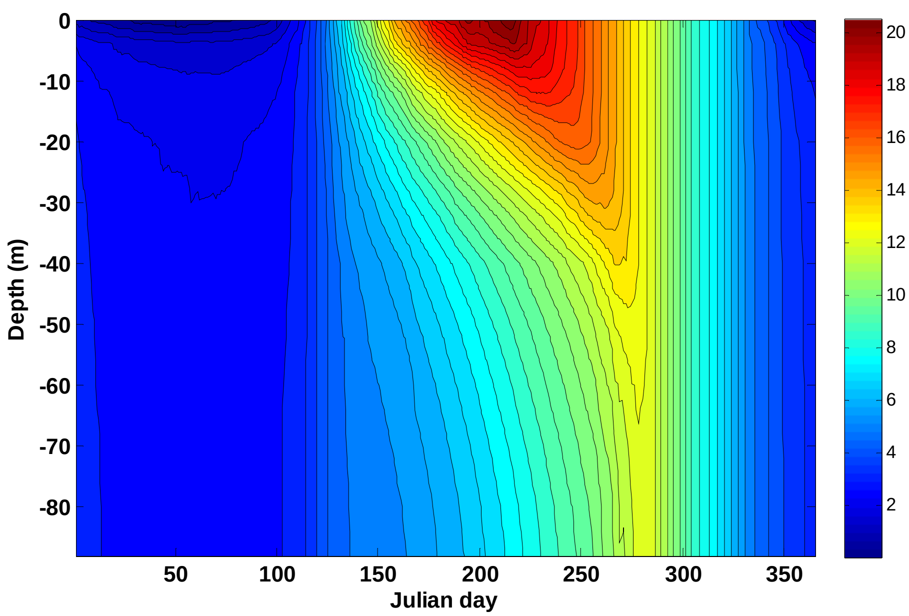
Figure 19. Modelled vertical distribution of water temperature in March 1st in Ristinselkä basin for 2070-2099. Average, maximum and minimum temperatures and standard deviation are calculated for different scenarios (a. A1B , b. A2 and c. B1) from 30 year´s data set.

Development of yearly stratification

In 2070-2099 the stratification of water layers during summer seem to be more pronounced with higher temperatures than during baseline (1971-2000) according to scenario A1B (Figures 20 a, b). Mixing period in spring seems to occur earlier than during baseline, and autumnal mixing period is longer due to delayed freezing.



a) 1971-2000



b) scenario A1B for 2070-2099

Figure 20. Water temperature isopleths in Ristinselkä basin, based on modeled daily mean temperatures a) during baseline (1971-2000) and b) according to scenario A1B in 2070-2099.

3. Fisheries production

3.1. The effect of climate change on the production of the most important fish species

The effect of climate change on vendace stocks was studied with currently available models. First, water temperature was forecasted based on climate scenarios by MyLake model. Then biological models of embryo development (Luczynski & Kirklewska 1984, Viljanen & Koho 1991) and bioenergetics (Helminen et al. 1990) were applied. The baseline period 1971-2000 was compared to period 2070-2099. Also some experimental works and field measurements related to this topic are under way.

Part of this bioenergetics modeling work was done in the course in University of Jyväskylä (Bionergetics modeling, WETS502) where experts were educated to bioenergetics modeling. In this course focus was on climate change and how models could be used in assessment of these changes. Participants were S. Aaltonen, A. Granqvist, T. Muuri, J. Pulkkinen and T. Tapper.

According to models, climate change shifts spawning time to later than present. At present spawning of vendace takes place in October-November when water temperature is 4-6 °C. In the end of this century, the estimated time is in December (Fig 21). Furthermore, the incubation temperature is higher and water warms earlier in the spring than in present situation. Consequently, hatching time will not change. The water temperature in hatching time will be 3-4 °C higher than presently. This will affect the metabolic rate of larvae and will probably shorten the period that they survive without external feeding. Also the activity and food consumption of potential predators are expected to be higher.

In the experimental works during 2009-2010 vendace and whitefish eggs are incubated in controlled temperatures. These temperatures mimic different scenarios of water temperature in the future. After hatching, the survival of larvae is studied in the laboratory with different feeding levels in temperatures of each scenario. These experiments produce information of survival and growth of larvae in different hatching temperatures. In the field, apparent temperature during incubation of eggs and first weeks of larval period is measured with temperature loggers.

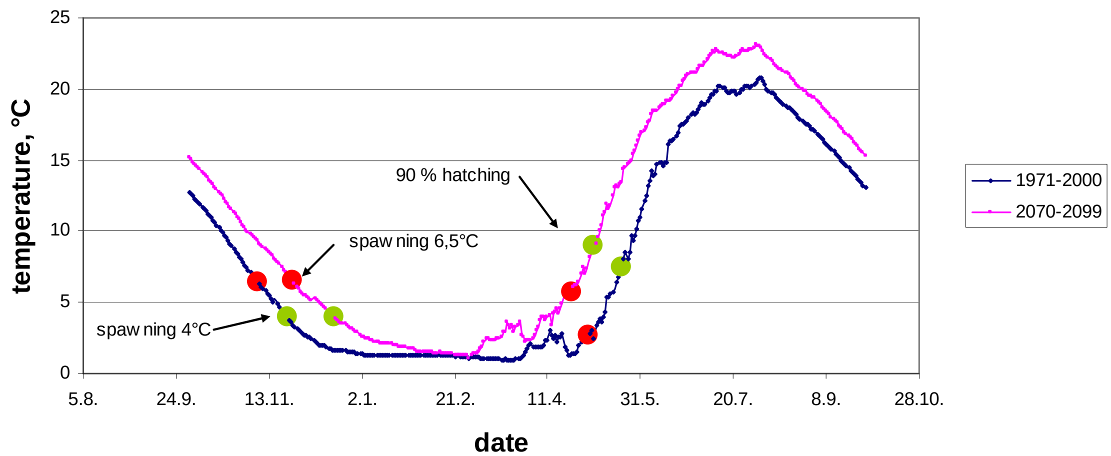
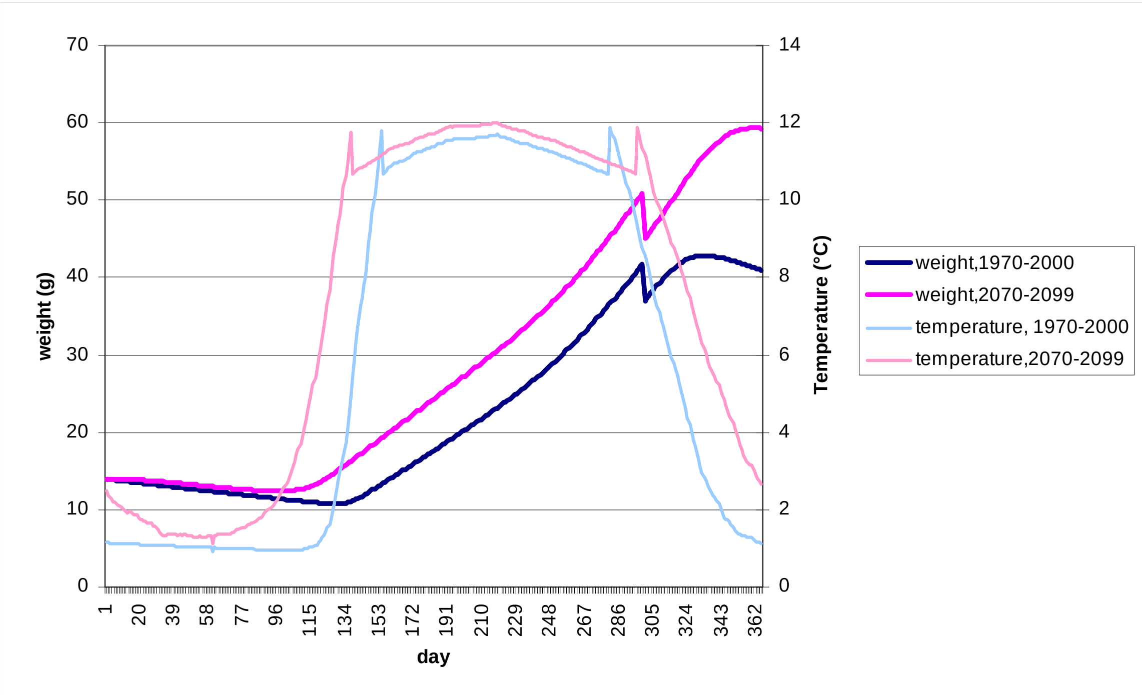


Figure 21. Spawning time and 90 % hatching time of vendace in 1971-2000 and 2070-2099. Water temperatures are based on MyLake-modelling and hatching time on models by Luczynski & Kirklewska (1984) and Viljanen & Koho (1994). Two different spawning temperatures (4 and 6.5 °C) are presented.

Bioenergetics modeling was used for estimating the effect of climate change on vendace growth and food consumption during second year of life (age group 1+) in Asikkalanselkä basin. The model was applied to average daily temperature in periods 1970-2000 and 2070-2099. Vendace growth and consequently food consumption was higher in the future scenario compared to present (Fig 22). The main reason is longer growing season. However, the calculation is simplified and includes several assumptions.

A



B

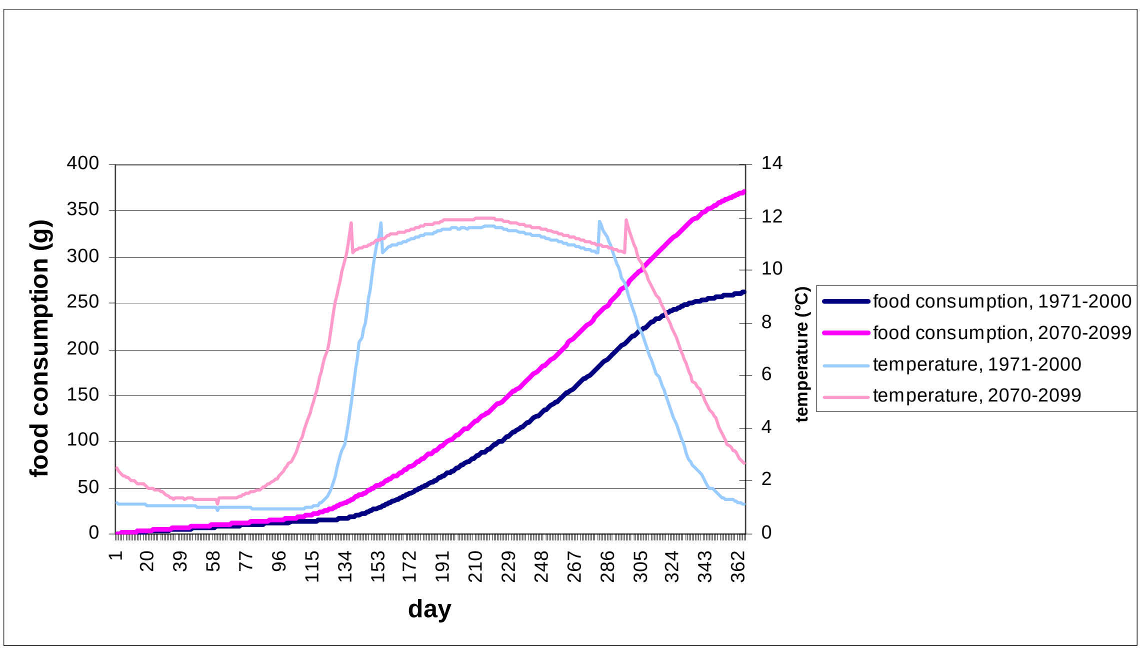


Figure 22. A) Weight and B) food consumption of vendace in Asikkalanselkä, southern Päijänne in based on bioenergetics modeling. Temperatures in 1971-2000 and 2070-2099 are estimated average preferred temperatures of vendace.

3.2. Effect on fishing operations

3.2.1. Professional fishing

Duration of ice cover will shorten or totally disappear in some years in the future. In years when ice cover occurs it will probably occur sporadically and will not allow safe transport. This change will have a prominent effect on professional fishing. Vendace is the most important single species for professional fishing. The proportion of winter seine catch from the annual commercial vendace catch varies spatially being over 30 % at maximum (Valkeajärvi & Salo 2000). In the future, this resource will be available at least partly for other fishing methods, e.g. trawling. Trawling is possible for longer period than presently. This means higher profitability of investments to trawling equipment and no need for investment to winter seining equipment. In years with some ice cover it is impossible to trawl throughout the winter. An open question is how market will react to longer period of availability of fresh vendace because in the present the main problem for professional fishermen is marketing of vendace.

3. 2.2. Recreational fishing

In recreational fishing the main target species on L. Päijänne are perch, pikeperch and pike when considering catch (Valkeajärvi & Salo 2000). All these species are expected to benefit from climate warming because their optimum temperatures are above present temperatures observed in L. Päijänne. Expected warming will not only accelerate the growth rate of individual fish but also increase the probability of strong year-classes. Summer temperature and year-class strength of perch and pikeperch are positively correlated (Sarvala & Helminen 1996, Lappalainen 2001). This leads to increasing resource available for recreational fisheries.

The disappearance of permanent ice cover will stop ice fishing but will allow other fishing methods (e.g. trolling) being used for a longer period. Also gill net fishing under ice will disappear but will be substituted by longer season for open water fishing. However, the target species can be partly different.

3.3. Synthesis of changes of fish production and fisheries

The preliminary results of applied models indicate that vendace reproduction will not be endangered by predicted climate change. Physiological processes of vendace are flexible and the predicted water temperatures are sufficient for successful reproduction. The critical point for vendace can be during summer stratification. Vendace is a visual feeder making daily vertical migrations feeding in epilimnion during dawn and dusk. If the temperature in the illuminated zone is high (> 20 °C), it is above the maximum temperature of food consumption. In the used bioenergetics model (Helminen et al. 1990) this maximum temperature was 15 °C for adult vendace. However, it is unknown how a short visiting in high temperatures affects feeding and physiology of vendace. The applied models do not include ecological interactions between species. These may be important factors regulating vendace stocks (Valkeajärvi & Marjomäki 2004).

According to used models, in thermally unstratified or weakly stratified lakes (e.g. Pyhäjärvi, SW Finland) water temperature in summer is too high and growth rate of vendace will be negative. This modeling result indicates that vendace stocks are not able to survive in these kinds of lakes.

For brown trout the predicted temperatures are critical. In 1990's an average number of days when temperature was over 20 °C was 23 in a summer. Based on MyLake modeling results in the end of this century it will be 66 days. This can cause extinction of natural brown trout populations in small streams. It is also worth to note that it has been used average temperatures in these bioenergetics modeling's and extreme warm years can be more severe.

Changes in fishing are species specific in many cases. As an example, fishing targeted for burbot is focused on winter time and is mainly gill net or trap net fishing. This fishing will probably disappear and consequently the fishing mortality of this species will decrease. At present, burbot stocks are probably overfished and so this change will benefit these stocks.

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