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River Kymijoki Ice Phenomena and Water Quality

Tom Kokkonen[1] and Matti Leppäranta[2]
Department of Physics, University of Helsinki
P.O. Box 48 (Erik Palmenin aukio 1), 00014 Helsinki, Finland
[1]tom.kokkonen@helsinki.fi, [2]matti.lepparanta@helsinki.fi

In this paper we will present results from field measurements at the River Kymijoki gathered during winter 2011/2012. River Kymijoki research project was started in fall 2011 and these results are part of the results that were made for master's thesis of Tom Kokkonen. River Kymijoki is located in southeast Finland, it freezes annually, and the catchment area of the river is 37 107 km^2 which is about 11 % of the area of Finland. The lake percentage of the river catchment is 19 %. Aim of this first stage of the research project was to select measurement points and evaluate their suitability to present the River Kymijoki ice and water quality phenomena. Other goal for the project was to examine the collected data and process a comprehensive image of the River Kymijoki ice phenomena and water quality.

1. Introduction

River Kymijoki freezes annually for approximately 3 – 5 months. Frazil ice causes problems every year and it is the biggest ice influenced problem at the River Kymijoki. There are a lot of industrial facilities and hydropower plants along the river and frazil ice blocks water intakes and water gate screens. Anchor ice is also causing problems in the River Kymijoki annually. Centre for Economic Development, Transport and the Environment installs approximately 20 frazil ice booms to prevent frazil ice problems (Väkevä 2004).

The River Kymijoki is located in southeast Finland and it is the fourth largest river in Finland by its discharge and catchment area. The catchment area is 37 107 km^2 which is 11 % of the area of Finland. Lake percentage of the river basin is 19.7 %, and one of the biggest lakes in Finland, Lake Päijänne, is in the catchment area. (Southeast Finland Regional Environment Centre 2008)

The river divides into two different main branches and both of them further divide into two different branches before the river reaches the Gulf of Finland, Baltic Sea. The length of the river is approximately 200 km and it drops 78.5 m across this distance. Regulation of the discharge between the two main branches is done by the automatic gate-structure dam.

The measurement points were chosen so that there are points at the main branch and all of the divided branches (Figure 1). Measurement points were named from Kymi1 to Kymi11. They were also chosen so that all of different flow conditions are covered. Some of the points are in the vicinity of frazil ice booms (Kymi3, -4, -5 and -6) (Figure 2), some are at freely flowing points (Kymi2 and -7) and some of the points are at the locations of annual anchor ice problems and anchor ice blastings (Kymi5) (Figure 3).

2. Material and methods

2.1 Expeditions

Research was made by field trips to River Kymijoki. Water quality was examined during open water season. The first field trip was made on 16 December 2011, when measurement points Kymi1 – Kymi7 were taken. Another field trip was made 16 January 2012, when points Kymi8 – Kymi11 were examined. Water quality, ice formation and structure were examined during the ice season. The first field trip was made on 24 February 2012, when points Kymi1 – Kymi3 were examined, and the second field trip was made on 12 March 2012, when points Kymi4 – Kymi7 were examined.

2.2 Observations

The sampling was made using an ice drill and an ice saw. The ice samples were stored in plastic bags and they were packed in a cold case with snow. Ice samples were analyzed later in a cold room at the temperature of -10 ^{o}C. The techniques that were used for analyzes are described in Langway (1958). The whole ice block was photographed on top of black canvas so different layers in the ice sample becomes visible. A vertical thick section was made and photographed on top of black canvas for the general structure and impurities of the specific sample. Then thin sections were prepared for analyzing the size and shape of the ice crystals. They were photographed between crossed polarized sheets where different ice crystals show up in different interference colors.

Water quality was examined by taking water samples for further chemical analyzes and hydrographic soundings. Soundings were made with CTD-90M (Sea & Sun Technology GmbH) for the fundamental physical and chemical properties of the water, and optical measurements were made with AC-9 (WET Labs Inc.), which gives information about optical quality of the river water and the mixing of the lake water to the river water. Data from the Kymijoki Water and Environment Association was also used in this research.

2.3 Weather and river discharge

Summer and fall 2011 were warmer than the average in the River Kymijoki region (Figure 4). At the beginning of year 2012 temperatures dropped suddenly which caused frazil ice problems. Minimum temperature in the winter 2012 was -28.2 °C (Finnish Meteorological Institute 2012). It was measured at Anjala, Kouvola at the lower part of River Kymijoki in 5 February 2012. Precipitation was much higher than normal in the early fall and December 2011 (Figure 4), which influenced a lot to the river discharge (Figure 5) and ice formation.

3. Results

3.1 Ice structure

Site Kymi1

There was only some border ice at site Kymi1. Total thickness of the ice was 22 cm and there was 5 cm of partly melted snow on top of the ice. The ice sample was taken from the western bank of the river. The sampling site was approximately 100 meters downstream from the hydropower plant. From the full vertical ice sample in Figure 6-a it can be seen that the ice was quite opaque ice except approximately 2 cm layer of clear ice at the bottom.

It can be seen from the thick section (Figure 6-b) that the opaque layer has a lot of gas bubbles. In the top 3 cm layer there is a cloudy band where the diameter of the bubbles was less than 1 mm. Next layer (3-10 cm from top) has less gas bubbles than the top layer and their diameter is 2-5 mm. These two layers have probably formed from melted snow. The next layer (10-19 cm from top) has a lot of round gas bubbles, which diameter is approximately 1 mm. The concentration of bubbles increases to the bottom so this layer has probably formed from frazil ice that was stuck on the border of river and frozen solid. Ice has pushed impurities downwards while freezing and that's why the concentration of gas bubbles increases to the bottom. The last 2 cm layer at the bottom is clear ice with no impurities.

It can be seen from the thin section (Figure 6-b) that the top layer (0-19 cm) has a lot of small rounded and needle like grains which diameter is approximately 1-3 mm. At the bottom 2 cm layer there is congelation ice that has columnar grains. Grains are approximately 5 mm wide and 20 mm long.

Site Kymi2
At the sampling site Kymi2 there was a stationary ice cover on the river. The total thickness of the ice was 32 cm and there was 15 cm of snow on top of the ice. In the middle of the river snow was partially melted. Ice sample was taken from the middle of the river. From the full vertical ice sample in Figure 7-a it can be seen that approximately 20 cm from top is quite opaque ice and the bottom 12 cm is clear ice. Different layers are visible in opaque part. In the middle of the sample there was a bit more brown section where probably are some sediments in the ice.

From the thick section samples in Figures 7-b and 7-c it can be seen that there is a lot of small gas bubbles which diameter is less than 1 mm and they form cloudy bands. There are also bigger gas bubbles (diameter approximately 5 mm) that are quite uniformly distributed at the opaque snow ice and frazil ice. Top layer (0-2 cm from top) has only small gas bubbles and it is probably formed of snow. At the bottom part of the opaque ice (over 16 cm from top) there are two layers where gas bubble concentration increases to the bottom. One of these layers has probably been the first ice layer that has formed from the frazil ice.

It can be seen from the thin sections (Figures 7-b and 7-c) that the opaque part has really small snow ice and frazil ice grains which diameter is approximately 1-5 mm. at 12-13 cm from top there is a layer that has larger columnar grains. This layer has probably formed from water that has flooded on top of ice. The bottom 8 cm layer is congelation ice and the grains are columnar. The width of the grains is 3-10 mm and they are as long as the congelation ice layer.

Site Kymi3
At the sampling site Kymi3 there was only some border ice and steadier ice cover at the bend of the river. The total ice thickness was 32 cm and there was 30 cm of snow on top of ice. The ice sample was taken from the river bend from the northern bank of the river. From the full vertical ice sample in Figure 8-a it can be seen that the ice sample is quite clear ice. There are few gas bubbles only in the top 10 cm layer.

It can be seen from the thick section samples (Figures 8-b and 8-c) that there are only few gas bubbles with diameter of approximately 1-2 mm. This indicates that the ice had formed in quite steady conditions. Some bed sediments can be seen throughout the sample.

From the thin sections (Figures 8-b and 8-c) it can be seen that the whole ice sample was congelation ice with columnar grains. On top layer (0-20 cm from top) grains are approximately 5-20 mm long and 1-5 mm wide. At the bottom of the sample grains are bigger. They are 5-30 mm long and 3-10 mm wide. Grains are geometrically randomly oriented at the whole sample.

Site Kymi4
At the sampling site Kymi4 there was only some border ice. The total ice thickness was 22 cm and there was 10 cm of snow on top of the ice. The ice sample was taken from the southern bank of the river. Sampling site was approximately 20 meters downstream from gate-structure dam. From the full vertical ice sample in Figure 9-a it can be seen that the top 11 cm is opaque ice with a lot of gas bubbles and the bottom 11 cm is quite clear ice. There is a cloudy band layer 14-16 cm from top.

It can be seen from the thick section (Figure 9-b) that the first 11 cm contains a lot of small gas bubbles (diameter < 1 mm). There is a clear layer 0.5-2 cm from top. There are bed sediments in the layer that is 2-7 cm from top. This layer is probably the first ice layer which is formed from the frazil ice that was attached to the bottom and bed sediments stuck on it before it reached enough buoyancy to float. The bottom 11 cm layer is quite clear with few cloudy bands.

It can be seen from the thin section (Figure 9-b) that the top 11 cm has really small grains (diameter < 1 mm). This layer has formed from the frazil ice. There is a layer (0.5-2 cm from top) where there are much bigger grains (5-10 mm long and 1-5 mm wide). This layer has probably formed from the water that flooded on top of the ice. The bottom 11 cm layer is congelation ice where the grains are columnar (10-40 mm long and 1-10 mm wide).

Site Kymi5

At the sampling site Kymi5 there was a stationary ice cover. The total ice thickness was 55 cm and there was approximately 23 cm of snow on top of the ice. Sampling site was approximately 20 meters downstream from frazil ice boom that was broken during the winter because of high surface flow. From the full vertical ice sample in Figure 10-a it can be seen that the whole ice sample is opaque ice with a lot of gas bubbles. At the lower part of the sample (40-55 cm from the top) there are a lot of bed sediments. The ice sample broke into three pieces (0-4 cm, 4-20 cm and 20-55 cm). Top layer (0-4 cm) broke during the processing so it wasn't analyzed.

It can be seen from the thick section (Figures 10-b, 10-c and 10-d) that the top 5-10 cm layer has a lot of small (< 1 mm) gas bubbles in horizontal rows. This layer was probably formed from the snow. Next 10 cm layer has few more clear layers where is only few small (< 1mm) gas bubbles and opaque layers that has a lot of gas bubbles which diameter is approximately 1 mm. Some of these layers are probably the first ice layer and it has pushed the bubbles downwards when it froze. Rest of the ice sample has a lot of small (< 1 mm) gas bubbles which are in bunches with more clear ice in between. This layer has probably formed from the frazil flocs which froze under the solid ice cover.

It can be seen from the thin section (Figures 10-b, 10-c and 10-d) that the top layer (4-5 cm from top) has columnar grains (2-10 mm long and 1-5 mm wide). This layer has probably formed from snow that was melted because of the rain or warm weather. Next layer (5-10 cm from top) has small rounded grains which diameter is approximately 1-3 mm. Rest of the sample has really small grains (< 1 mm) that layer has probably formed from frazil ice.

Site Kymi6

There was a stationary ice cover at the sampling site Kymi6. The total ice thickness was 35 cm and there was 15 cm of snow on top of the ice. At the middle of the river there was some partly melted snow. From the full vertical ice sample in Figure 11-a it can be seen that the top 15 cm layer is opaque ice with a lot of gas bubbles and the rest of the ice is quite clear ice.

It can be seen from the thick section (Figures 11-b and 11-c) that the top 3 cm layer has a lot of small (< 1 mm) gas bubbles. Next layer (3-10 cm from top) has a lot of vertical gas catchments which are 3-20 mm long and 1 mm wide. These layers have formed rapidly because of really cold temperature and ice could not push the gas bubbles away when it froze. Rest of the sample is quite clear ice with only few small (< 1 mm) gas bubbles.

It can be seen from the thin section (Figures 11-b and 11-c) that the top 0.5 cm layer has grains which diameter is approximately 3 mm. Next 0.5 cm layer has one big grain which is approximately the size of the whole layer. These layers were probably formed from the water that flooded on top of the ice or melted snow. Next layer (1-3 cm from the top) has small grains (diameter 1-3 mm). Rest of the sample is congelation ice. At the top of the congelation ice layer (3-16 cm from top) there are columnar grains which geometrical alignment is vertical. Grains are 20-50 mm long and 3-10 mm wide. There are also some frazil ice grains in between. Bottom part of the congelation ice (16-35 cm from top) has grains which are 2-30 mm long and 1-5 mm wide. Geometrical alignment is more random with these grains.

Site Kymi7
Sampling site Kymi7 was free of ice.

4.2 Water quality

Turbidity and sediments in the current
Both turbidity and sediment concentration are highly dependent of erosion and runoff, and therefore peaks occur often after rain events. Sediments are also dependent of primary production in the river and lakes that can be seen in high values during June 2012 (Figure 12). Turbidity is determined mostly from the runoff, and the influence of the high precipitation at the end of the year 2011 is clearly visible in the figures. Some points also show peak in sediment concentration at that same time (Figure 14). Turbidity and sediment level increase when moving downstream (Figure 13).

Optical properties
From studying optical properties of water, we can examine dissolved colored organic matter (CDOM), chlorophyll *a*, and the amount of suspended particles. Different impurity categories attenuate light at different wavelengths, and thus we can determine the concentrations of these categories from the measured spectrum. CDOM attenuates at short wavelengths (400-500 nm) and is seen in the measurements, while attenuation due to suspended particles depends on the quality of the particles and in general has weaker wavelength dependency than CDOM. Photosynthesis shows at wavelengths 430-440 nm and 660-690 nm (Myrberg et al. 2006). In the data obtained there was no noticeable peak in these bands, however, that may be due to low levels of chlorophyll *a* or too strong role of CDOM and suspended matter.

It can be seen from the scattering spectra (Figure 15) that the concentration of particles increases downstream. Upstream points have quite low scattering level except for Kymi7 that is downstream from a water treatment plant. In the upstream points (Kymi9, 10 and 11), attenuation and absorption was so low that scattering could not be estimated from the measurements.

Scattering was quite uniform at all wavelengths during the winter and there was much less scattering except at site Kymi4. Absorption and attenuation were much lower at every point during winter except at point Kymi3 (Figure 16).

5. Conclusions

There was a lot of variation in the ice structure and thickness between different measurement points, because of ice control structures and different discharge. Ice structure at measurement points is shown in Table 1 and Figure 17.

At the measurement points, where the river discharge was higher (> 200 m^3/s) there was only some border ice (Kymi1, -3 and -4) or no ice at all (Kymi7). Frazil ice boom seemed to work well at measurement point Kymi3, where the ice cover was entirely congelation ice. Frazil boom had formed insulating ice cover upstream from point Kymi3 and there was no frazil ice flow to the measurement point. Frazil boom upstream from point Kymi4 didn't seem to have noticeable effect on the ice structure.

At the measurement points, where the river discharge was lower (< 200 m^3/s), there was a stationary ice cover. Frazil ice boom seemed to work well and it collected flowing frazil ice at downstream from measurement point Kymi5, where ice cover was entirely frazil ice. It was also the thickest ice cover (55 cm) of all the measurement points. Also the frazil boom upstream from the measurement point Kymi6 seemed to work well. Ice structure showed that there were really cold periods but there was not much frazil ice in the ice sample. The frazil boom had formed a well insulating ice cover and there was no frazil ice flow to the measurement point.

Water quality was quite good in River Kymijoki, although there was a clear decrease in water quality downstream (Table 2). The water quality at the lower parts of the river was affected by the industrial facilities and water treatment plants. There was no difference in water quality between the two main branches, and there was no noticeable stratification in the water quality because of the mixing in the turbulent flow. Scattering of light was much lower during the winter, and in the upper part of the river there was no noticeable scattering even in the open water season.

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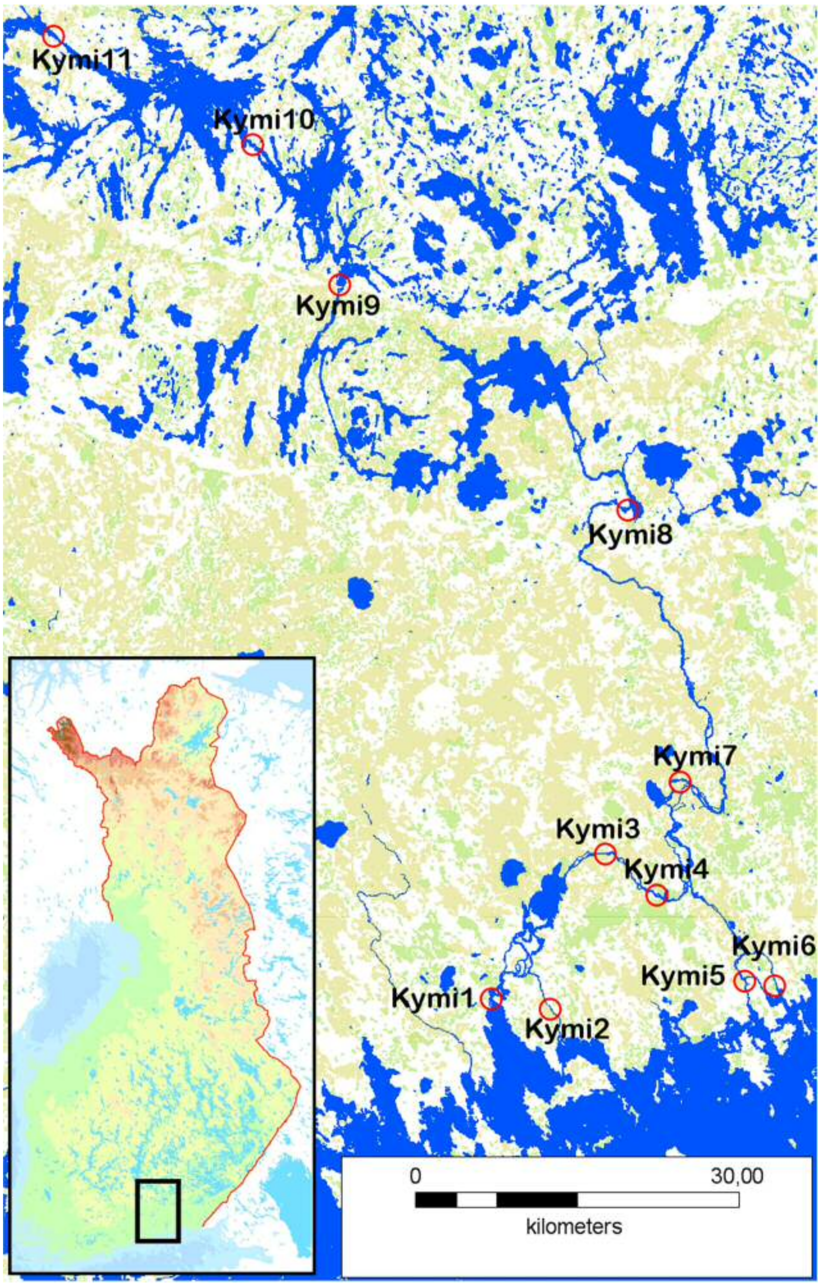


Figure 1. Measurement points at the River Kymijoki (map info: National Land Survey of Finland 2012).

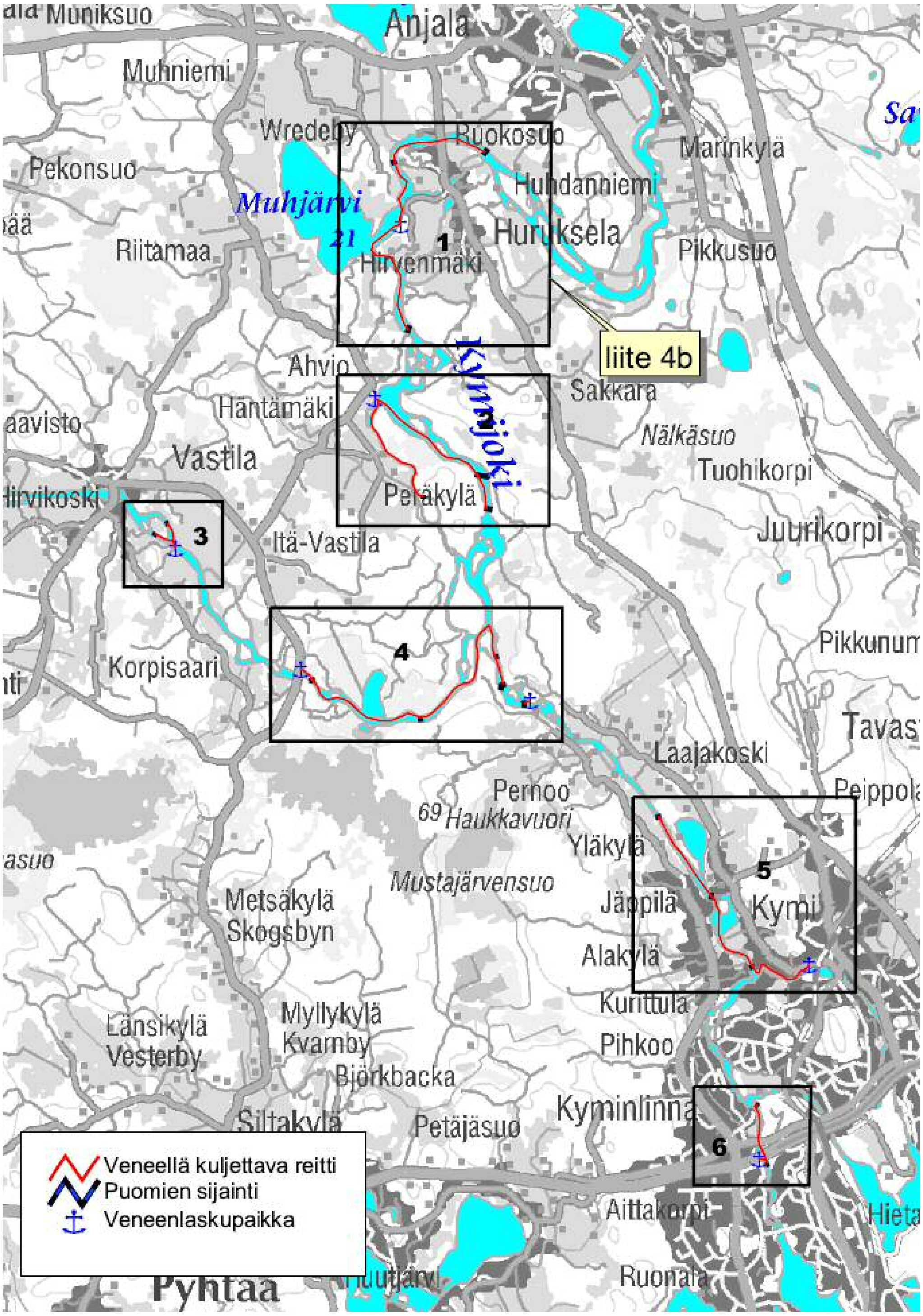


Figure 2. Frazil booms at the River Kymijoki (frazil booms are marked with black dot) (Väkevä 2004).

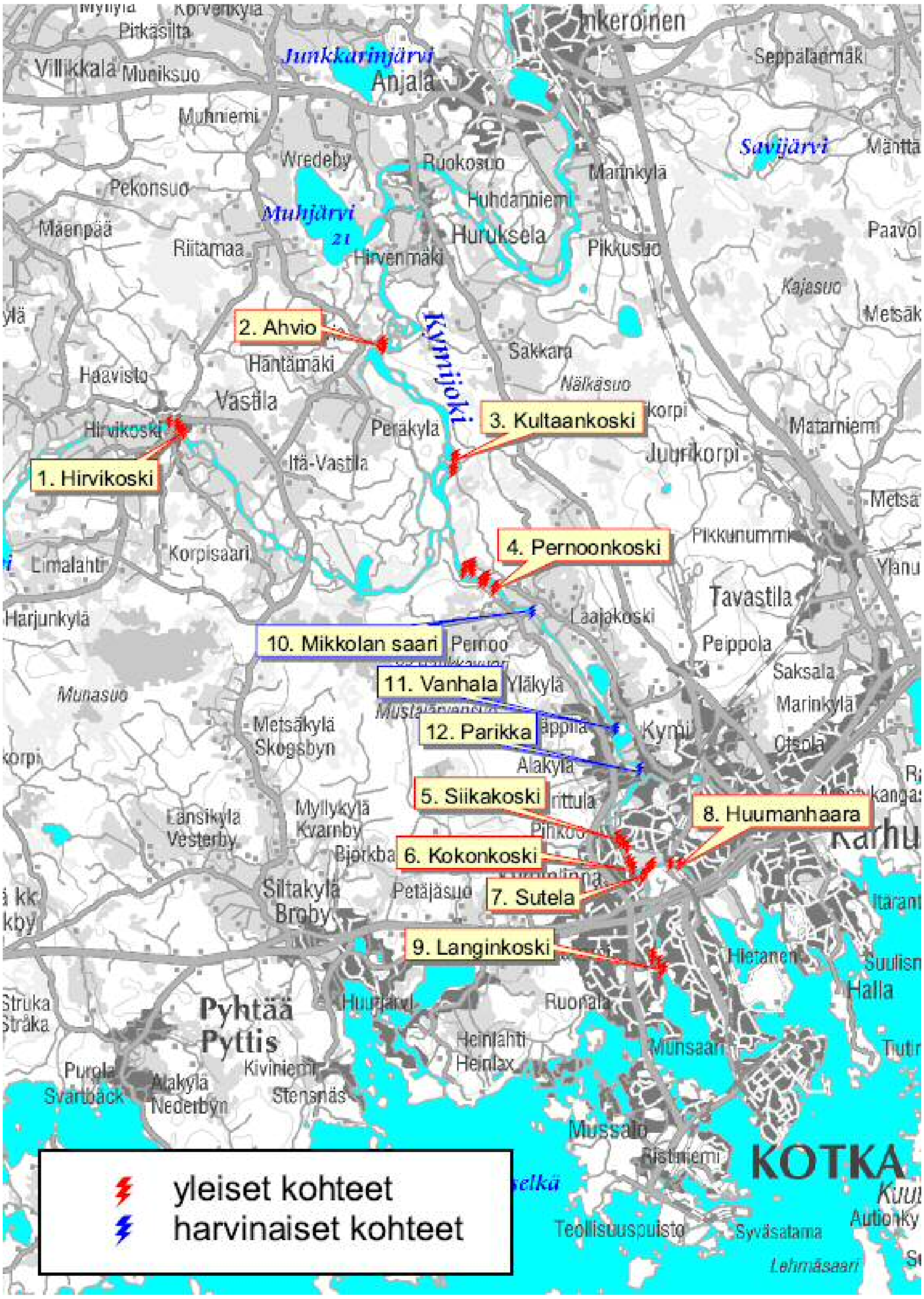


Figure 3. Anchor ice blasting at the River Kymijoki (red marks: common places of blastings, black marks: rare places of blastings) (Väkevä 2004).

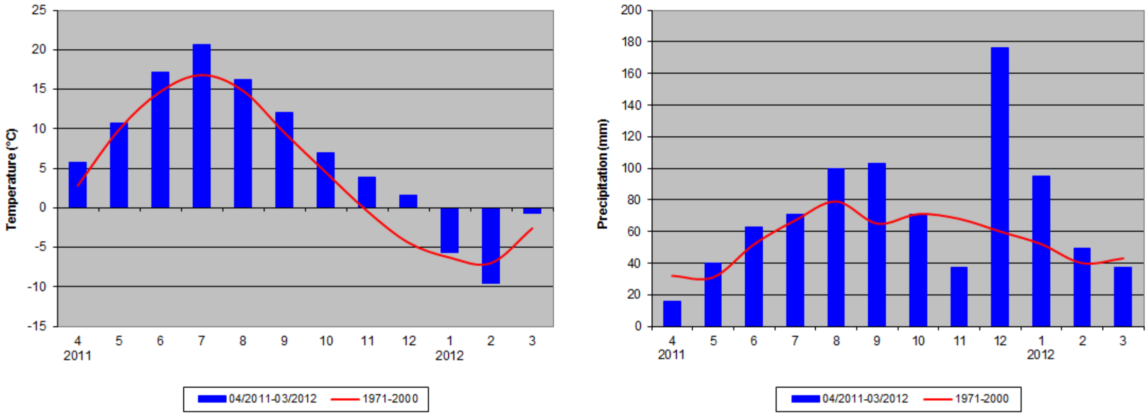


Figure 4. Temperature and precipitation in 4/2011-3/2012 and long-term averages (1971-2000) at Anjala, Kouvola (lower part of the River Kymijoki) (Finnish Meteorological Institute 2011 and 2012).

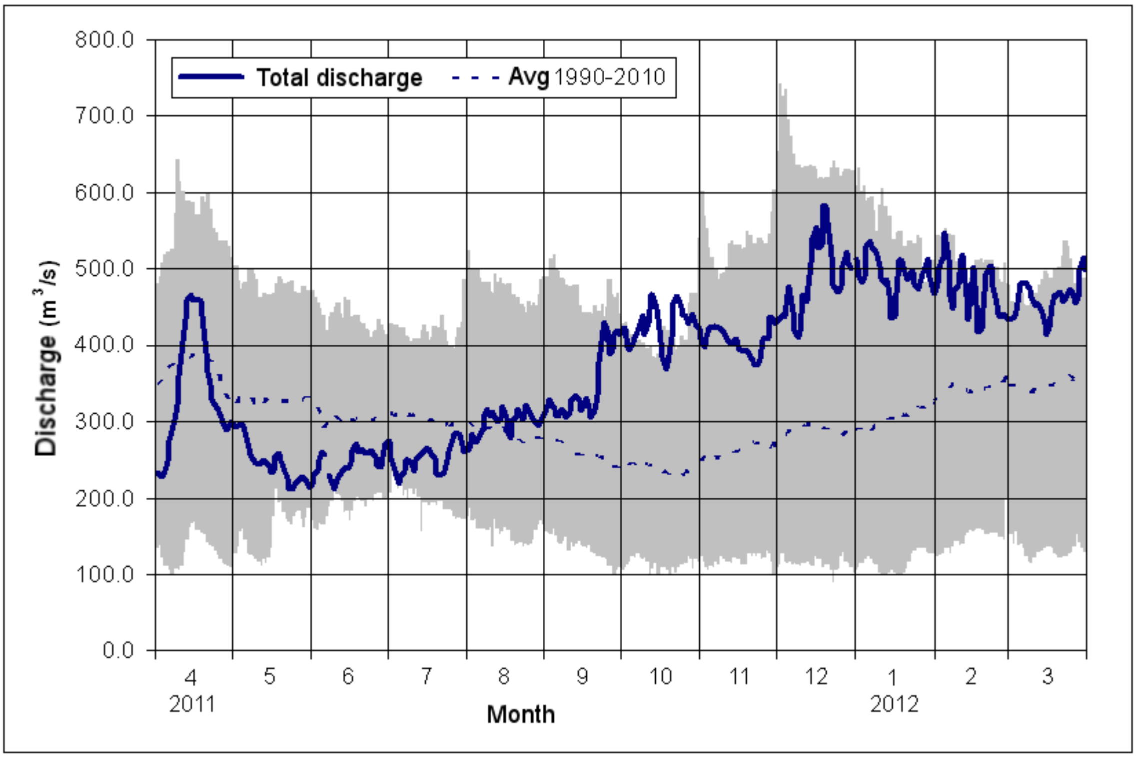


Figure 5. Total discharge at the River Kymijoki 1 April 2011 – 31 March 2012, long-term average (1990-2010) (dotted line) and range (1990-2010) (gray area) (OIVA - Environment and geographical information service for specialists 2012).


a)
0-22 cm

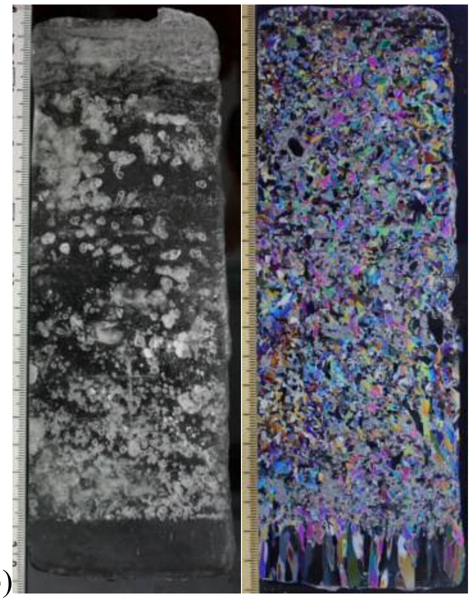

b)
0-22 cm

Figure 6. Kymi1 ice samples a) whole ice block, b) thick sample in normal light (left) and thin section in polarized light (right).

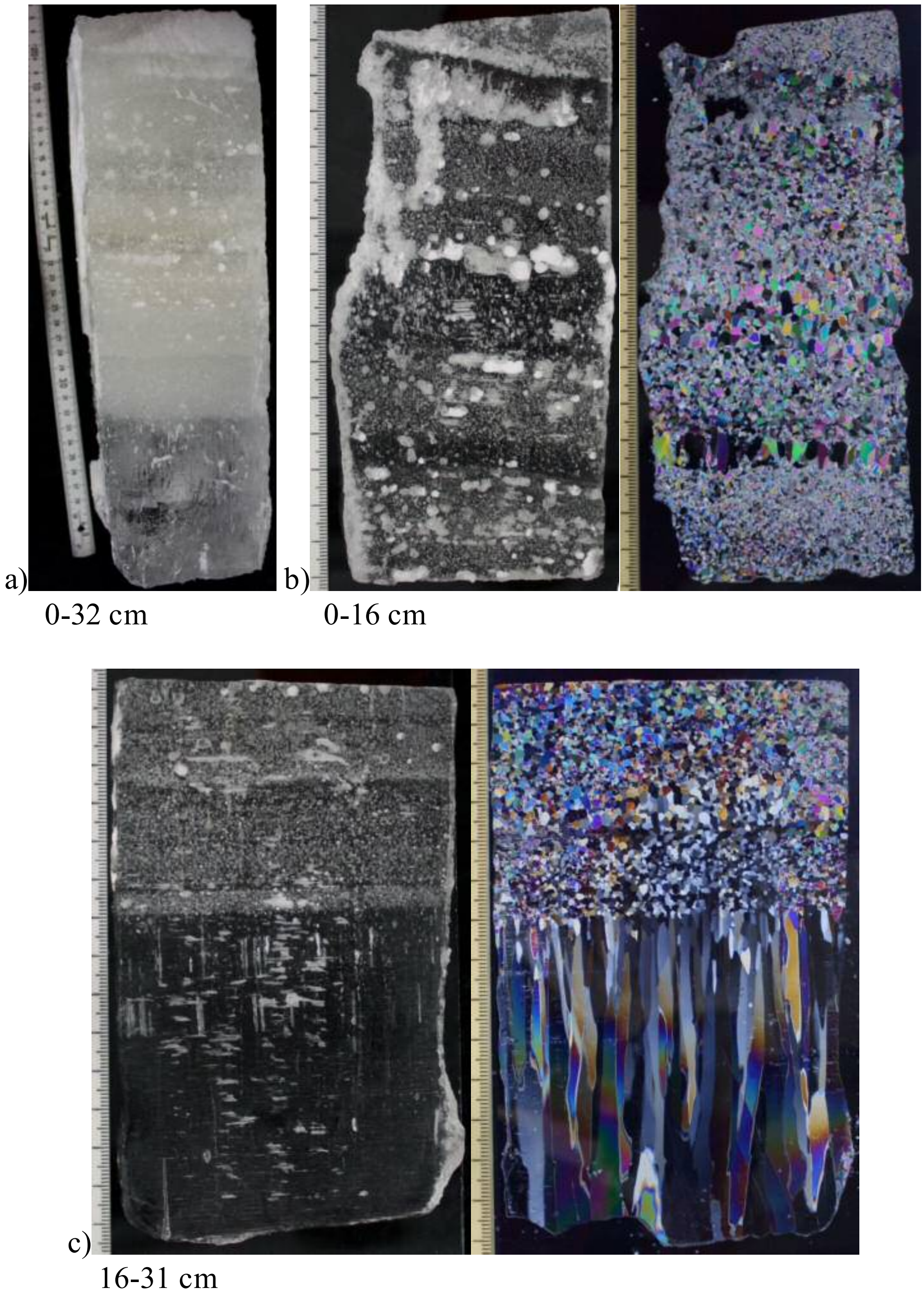


Figure 7. Kymi2 ice samples a)whole ice block, b) and c) thick sample in normal light (left) and thin section in polarized light (right).

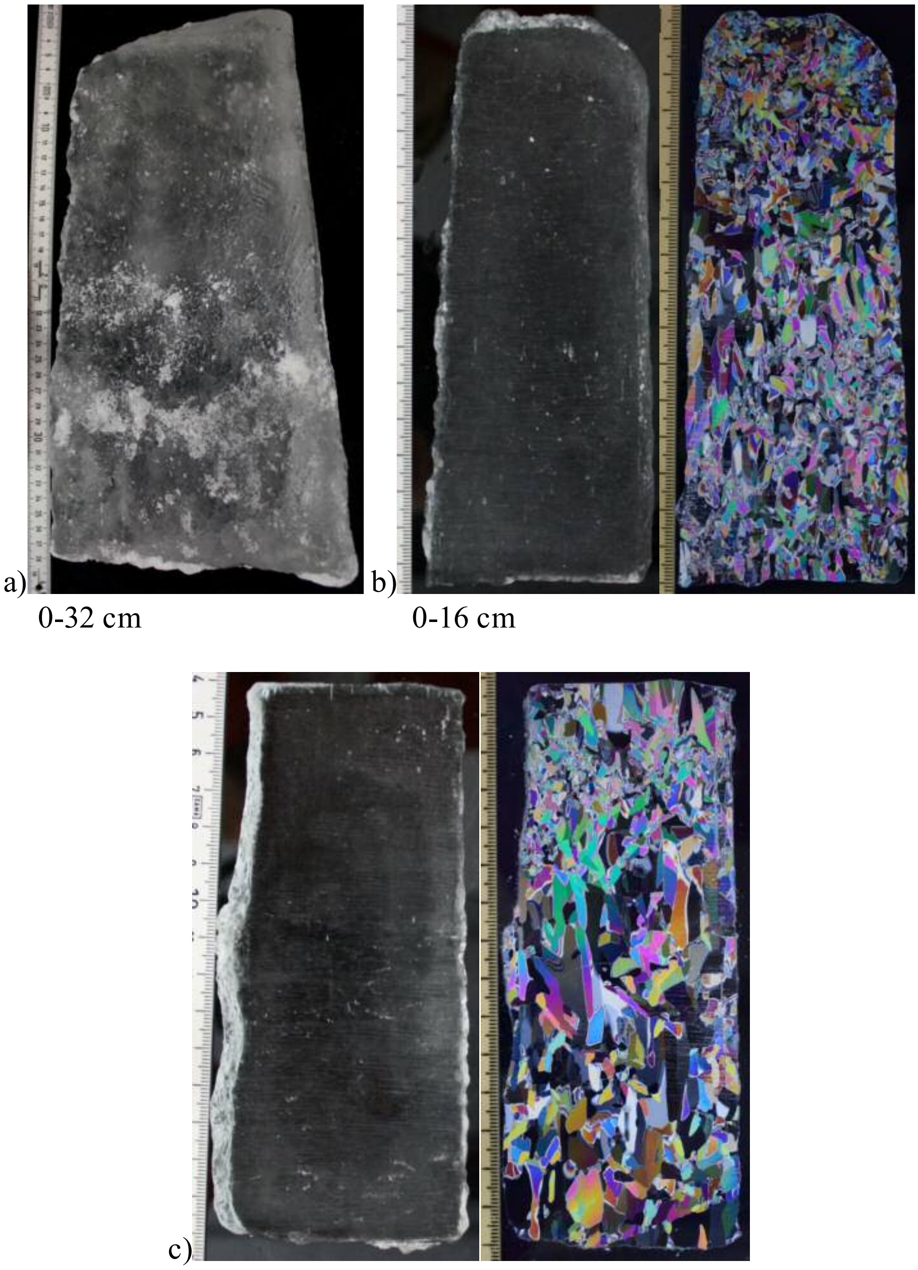
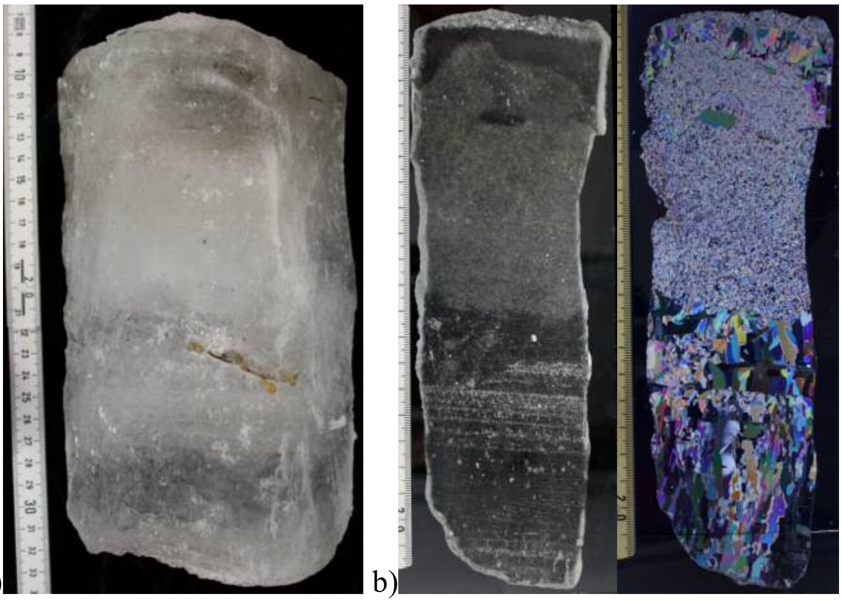
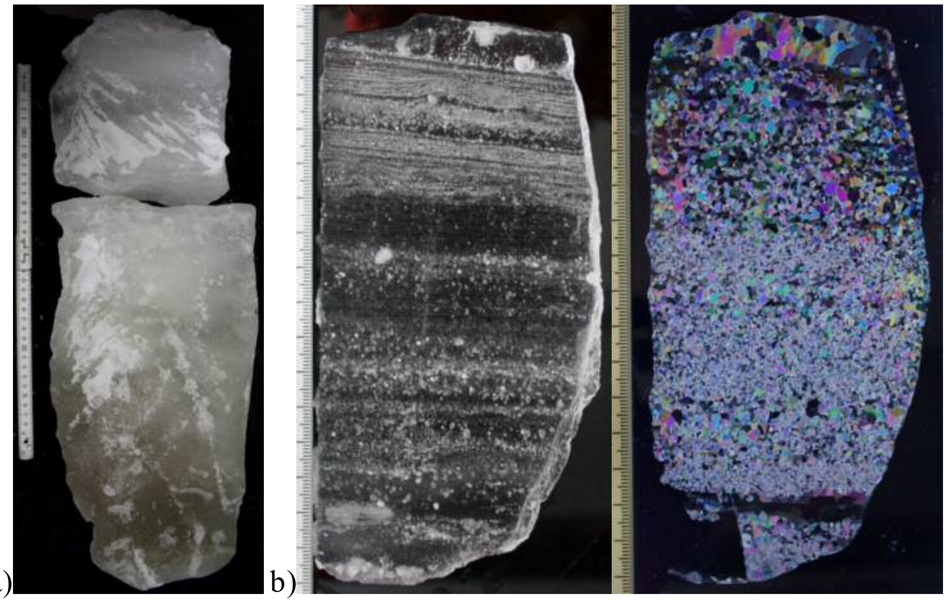


Figure 8. Kymi3 ice samples a)whole ice block, b) and c) thick sample in normal light (left) and thin section in polarized light (right).

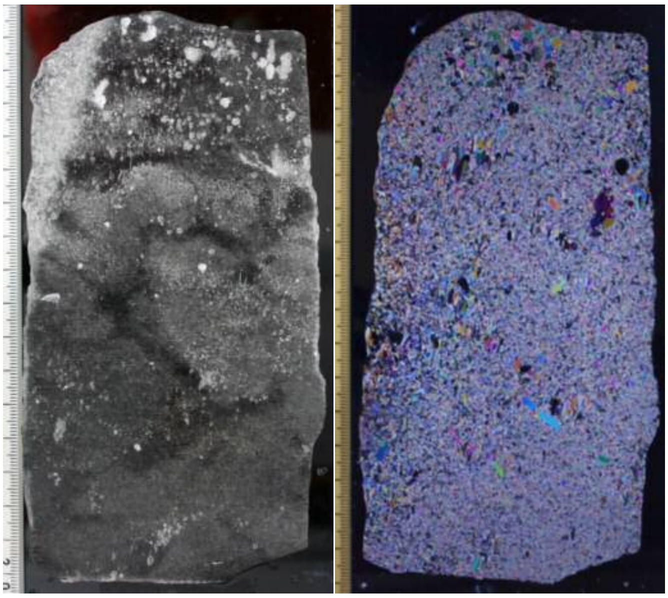


a) 0-22 cm   b) 0-22 cm

Figure 9. Kymi4 ice samples a) whole ice block, b) thick sample in normal light (left) and thin section in polarized light (right).

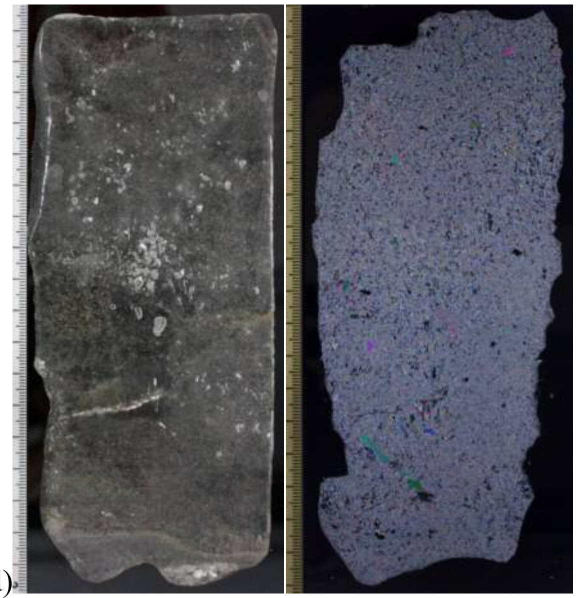


a) 0-55 cm   b) 4-20 cm



c)

20-37 cm



d)

37-55 cm

Figure 10. Kymi5 ice samples a) whole ice block, b), c) and d) thick sample in normal light (left) and thin section in polarized light (right).

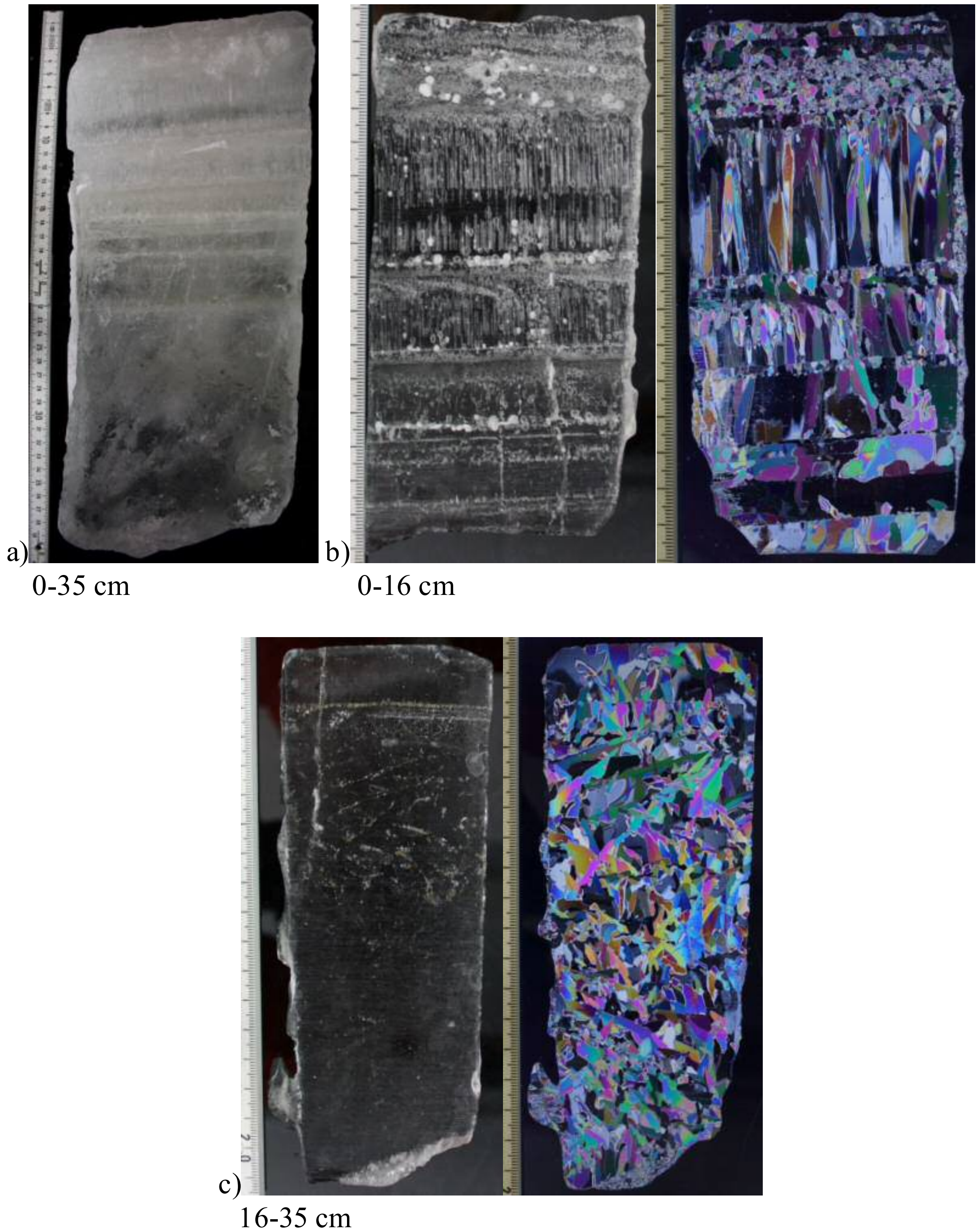


Figure 11. Kymi6 ice samples a) whole ice block, b) and c) thick sample in normal light (left) and thin section in polarized light (right).

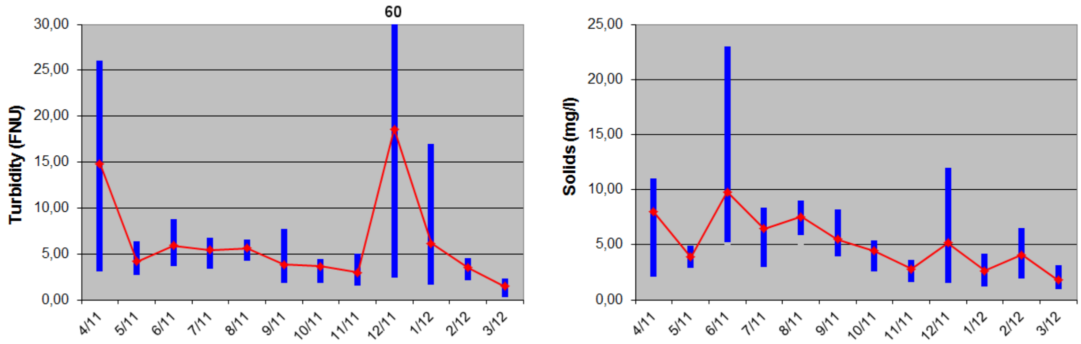


Figure 12. Turbidity and solids at River Kymijoki (4/2011-3/2012). Red line is average and blue column is range (OIVA - Environment and geographical information service for specialists 2012).

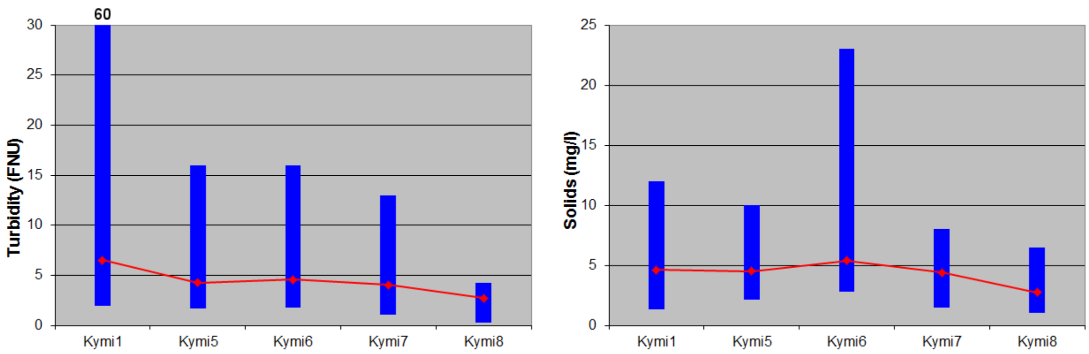


Figure 13. Turbidity and solids at different measurement points at the River Kymijoki (4/2011-3/2012). Red line is median and blue column is range (OIVA - Environment and geographical information service for specialists 2012).

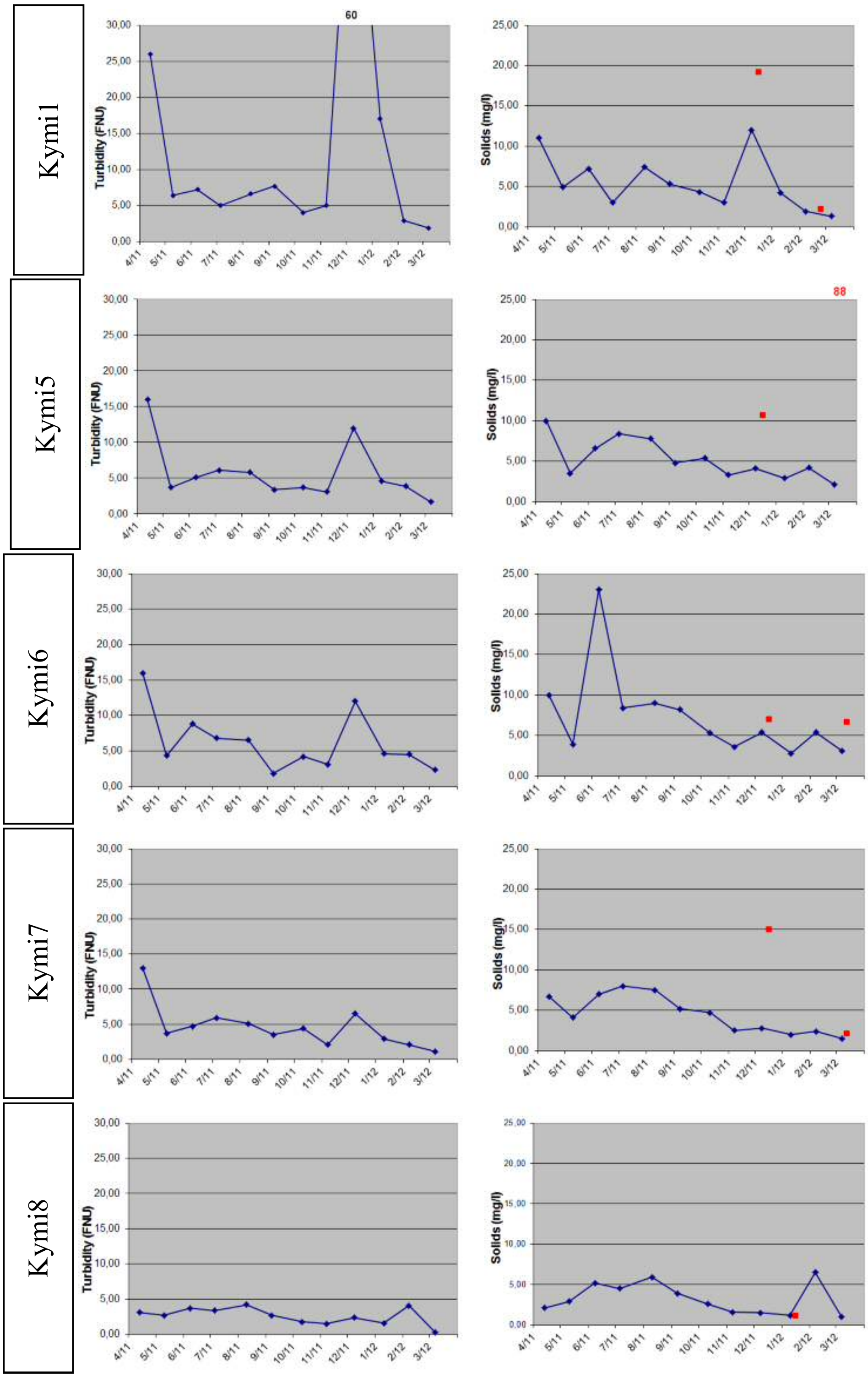


Figure 14. Turbidity and solids at the River Kymijoki measurement points (blue line is Kymijoki Water and Environment Associations measurements, red dots are own measurements) (OIVA - Environment and geographical information service for specialists 2012).

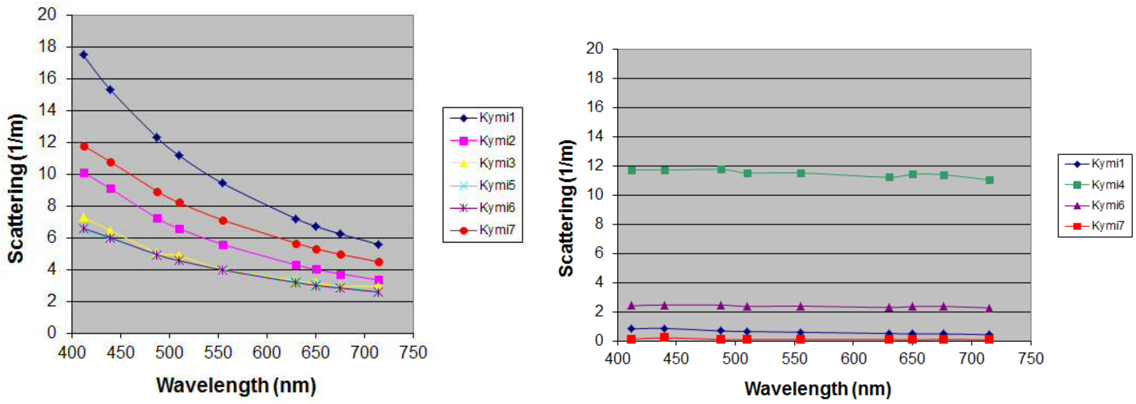
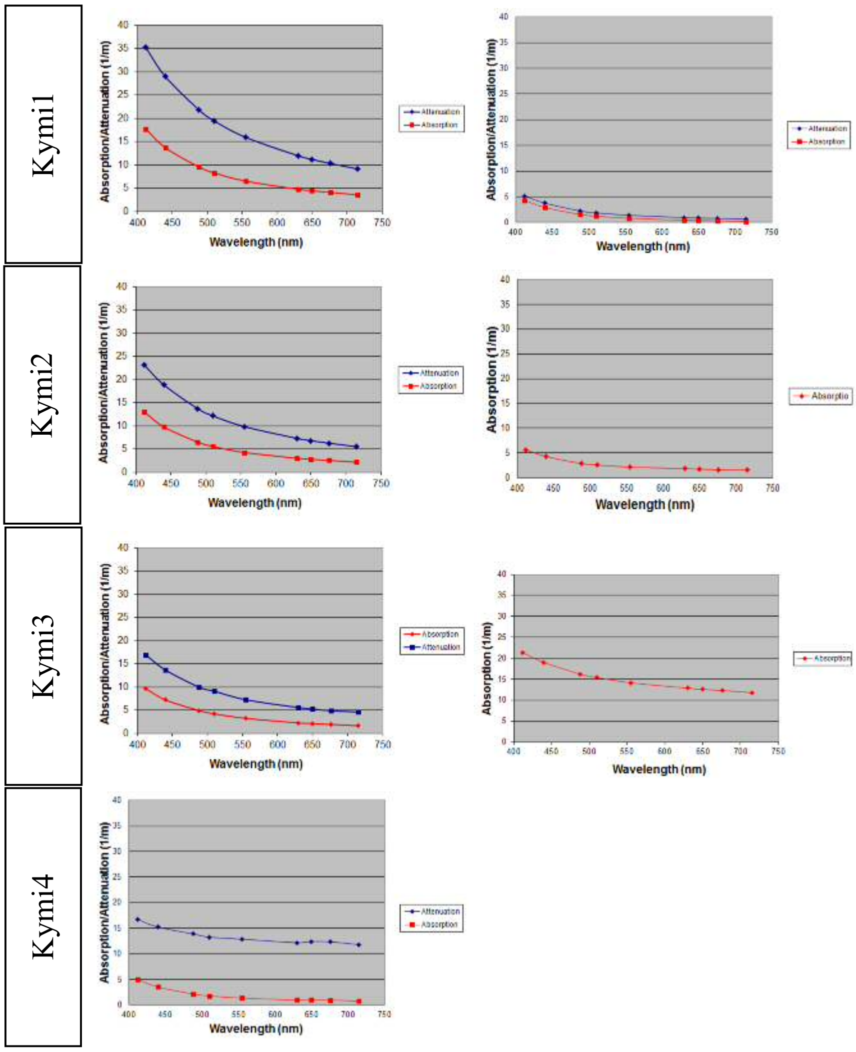


Figure 15. Scattering at the River Kymijoki measurement points during open water season (left) and during ice season (right).



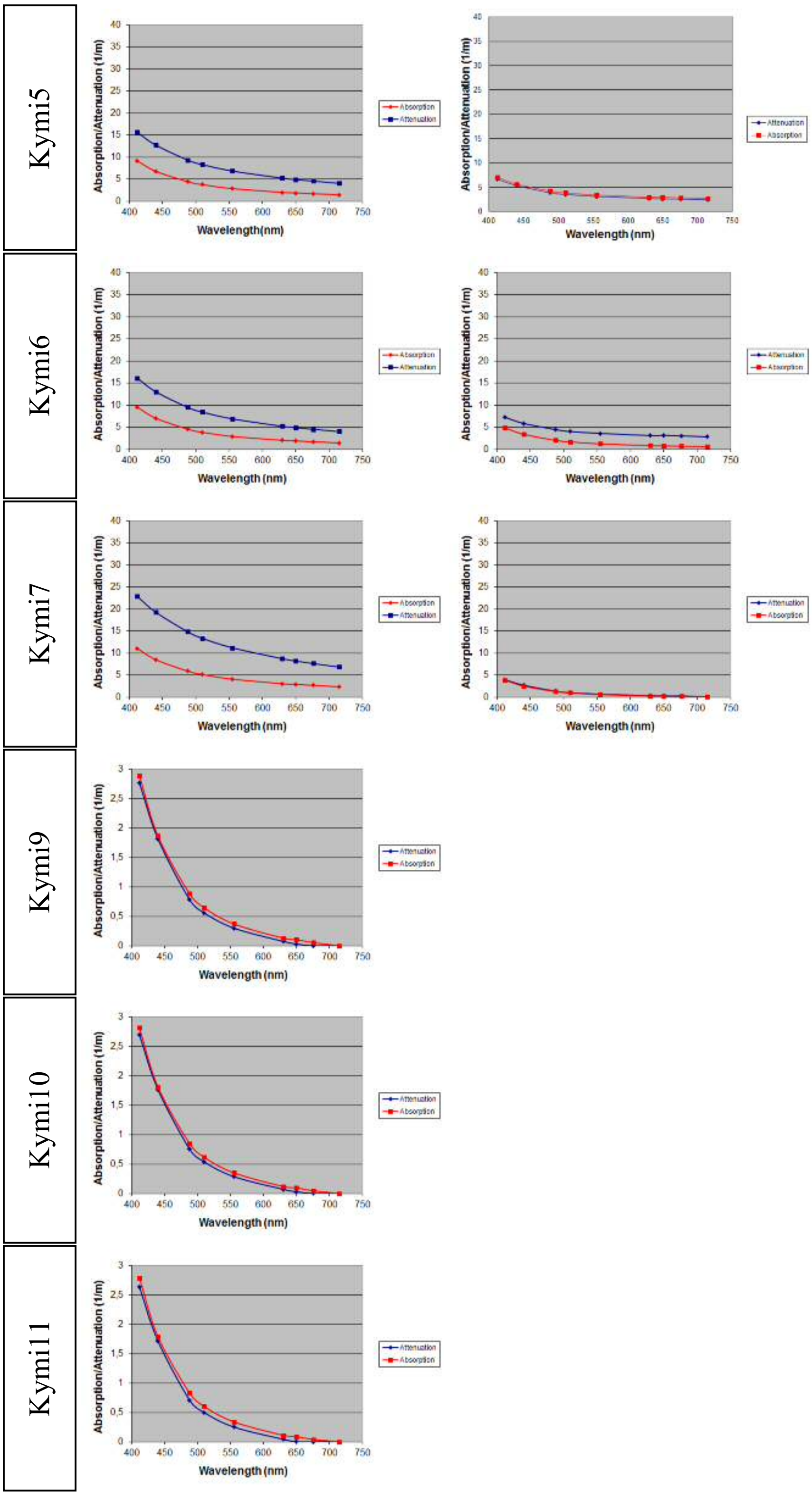


Figure 16. Absorption (red line) and attenuation (blue line) at different River Kymijoki measurement points. Open water measurements at left and ice season measurements at right.

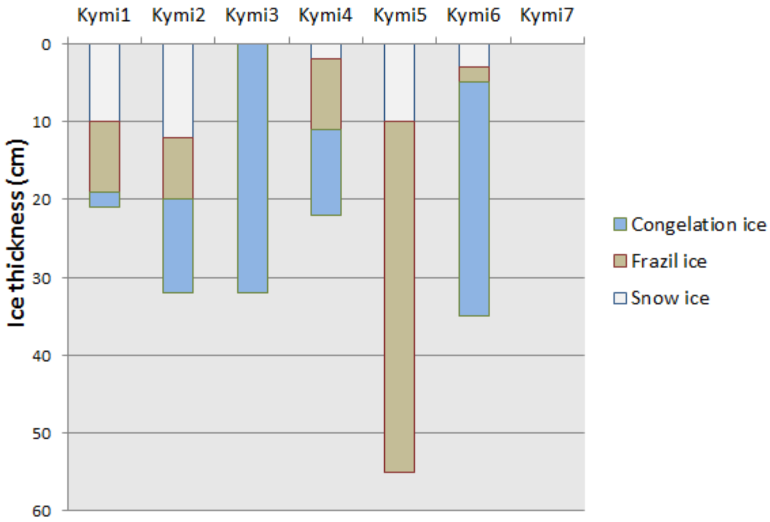


Figure 17. Ice structure at River Kymijoki measurement points.

Table 1. Ice structure at River Kymijoki measurement points.

	Kymi1	**Kymi2**	**Kymi3**	**Kymi4**	**Kymi5**	**Kymi6**	**Kymi7**
Snow ice	10	12	0	2	10	3	0
Frazil ice	9	8	0	9	45	2	0
Congelation ice	2	12	32	11	0	30	0
Total thickness	21	32	32	22	55	35	0

Table 2. Water quality at River Kymijoki measurement points. Values are median values from 4/2011-3/2012 values (OIVA - Environment and geographical information service for specialists 2012). Kymi2, 3, 4, 9, 10 and 11 are average values from two own measurements.

	Oxygen saturation %	**Oxygen, dissolved (mg/l)**	**Turbidity (FNU)**	**Solids (mg/l)**	**pH**	**Electrical conductivity (mS/m)**
Kymi1	93	11,4	6,5	4,6	6,9	7,90
Kymi2				7,6	7,0	6,63
Kymi3				87,7	6,9	6,50
Kymi4				20,4	8,2	5,93
Kymi5	95	11,6	4,3	4,5	7,0	7,85
Kymi6	91	11,4	4,6	5,4	6,9	7,90
Kymi7	93	11,5	4,1	4,4	6,9	7,80
Kymi8	91	11,6	2,7	2,8	6,9	6,90
Kymi9				0,4	7,2	5,46
Kymi10				0,7	7,0	6,18
Kymi11				0,7	7,1	5,70