Lake Ladoga: life under ice

Interplay of under-ice processes by global change

A Russian-Swiss multi-disciplinary project

Images of ice-covered Lake Ladoga on 21st March 2012 (left) and 25th March 2007 (right)

Scientific institutions:
Northern Water Problems Institute (NWPI), Karelian Research Center RAS, Petrozavodsk
Limnological Institute (IL), RAS, St-Petersburg
Arctic and Antarctic Research Institute (AARI), St-Petersburg
Nansen International Environments and Remote Sensing Center (NIERSC), St-Petersburg
Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne
University of Geneva (UNIGE), Forel Institute, Geneva
Eawag, Dübendorf
University of Konstanz, Konstanz, Germany
Uppsala University, Uppsala, Sweden
UMR CARRTEL, Limniques/Alpine Research Centre on Lake Food webs, INRA-Thonon-les-Bains, France
1. Introduction

The Great European Lakes (Ladoga and Onego) have attracted increasing attention from both researchers and end-users (Rukhovets and Filatov, 2010). These lakes are important resources for drinking water, transport (Baltic Sea to White Sea and Caspian Sea), energy, use of biological resources and recreation. The challenges for their rational use and conservation includes pollutions and eutrophication from industries and domestic wastewater discharges, as well as impacts of alien species (invasive species) and global warming. Minimising these anthropogenic impacts, which jeopardize the quality of the already limited freshwater resources, is essential to sustain the well-being of the riparian population, as well as the downstream city of Saint-Petersburg. This necessity has triggered various scientific studies, in order to conserve, restore, and efficiently use the resources of these large lakes. The sustainable use of water and biodiversity resources in Lakes Ladoga and Onego was declared a high priority in 2013 by the Russian Security Council.

Winter limnology research has remained limited due to difficult field conditions, but have recently developed especially regarding global warming (Salonen et al. 2009, Bengtsson 2011, Twiss et al. 2007, McKay et al. 2011) and the annual heat budget of these lakes. Physical investigations carried out in wintertime so far have mainly focused on small and medium sized lakes of the Northern Hemisphere (Kirillin et al., 2012), whereas the winter regime of large and great lakes have been studied to a much lesser degree. One possible reason for the lack of winter observations in large lake systems is the practical difficulty to organize field surveys. Their ice-cover is usually not stable with numerous fractures, thermal cracks and ice holes (Kondratyev and Filatov 1999, Wang et al. 2006). Thus, progress in ice research remains slow, and winter processes in seasonally ice-covered lakes still remain a blank spot in modern limnology. “We know much more about tropical lake ecosystems and even about perennially ice-covered polar lakes than we do about energy and matter transport during the long winters in the temperate lakes of Eurasia and North America” (Shuter et al. 2012). One motivation for this increasing interest was provided by the question of the response of mid- and high-latitude lakes to global warming. Climate change issues necessitate a better understanding of the role played by ice-covered lake for the emission of greenhouse gases like methane into the atmosphere and for the global carbon (C) budget.

This research program propose to investigate physical and biogeochemical dynamics on ice-covered Lake Ladoga through interdisciplinary projects. Seven sub-projects will be conducted by experts from Russia, Switzerland, France, Germany and Sweden. The diversely represented research topics consist of water physics, chemistry, lake ecosystem, carbon cycling, paleolimnology and remote sensing.

1.1. Lake Ladoga

The largest European lake, Lake Ladoga, is situated North-East of Saint-Petersburg in Russia. With a surface area of 17'872 km², its catchment area is as large as 258'000 km². The maximum depth is 230 m in the northern part of the lake, while the mean depth is 51 m.
Since 1970, Lake Ladoga has changed from oligotrophic to mesotrophic conditions, and is slowly returning to a more oligotrophic state. It reached its maximum eutrophication in 1980s with phosphorus concentrations of up to 26 µgP/l due to industrial wastes and increasing population. In 1990s, the activities from polluting industries largely declined with the economic collapse. The water quality was further improved by an enforcement of the regulations to treat wastewater. However, even if the phosphorus inputs returned to acceptable levels, primary production in the lake remained mesotrophic. Studies (Petrova et al. 2010) showed that bacterioplankton and water fungi were degrading organic substances from the catchment, explaining the increased carbon turnover within the lake.

Scientific investigations on Lake Ladoga (Rukhovets and Filatov 2010) were mainly focused during the ice-free period and previous field studies under ice have only been fragmented (Kondratyev and Filatov, 1999, Runjantcev and Drabkova, 2002, Center of Arctic monitoring see http://www.spb-business.ru/show.php?directory=986). To fulfil this gap, research on key processes during the winter period are important. Our research program will therefore focus on understanding the functioning of Lake Ladoga ecosystem under ice.

1.2. Short description of seven sub-projects

The research program aims at investigating life under ice and relevant physical, chemical and biological processes. In particular, we would like to understand under-ice convections and its implication for ecosystem development. For this, four sub-projects will measure physical and biological parameters simultaneously under-ice. Instruments will be set on a mooring during the entire winter period. During the ice-covered period, traditional methods will be applied from ice holes. In addition, automatic underwater vehicles will allow to horizontally map the convection structures, and remote sensing from drones will identify spatial heterogeneity of the ice cover.

The functioning of the ecosystem will be further investigated by analysing phytoplankton, zooplankton and bacteria, as well as C transfer throughout the trophic system. Carbon dioxide accumulation and carbon cycling throughout the winter period will be assessed. The reconstruction of land use history in the catchment area will be explained using short sediment cores.
The detailed sub-projects are presented further below:

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2. Under Ice convection - from small-scale physical processes to large-scale biological implications

*Dr. Arkady Terzhevik, Northern Water Problems Institute, Karelian Research Center, Russian Academy of Sciences*

*Dr. Damien Bouffard and Prof. Alfred Wüest, APHYS - Margaretha Kamprad Chair, EPFL*

2.1. Background

Ice-covered lakes are associated with cold water, which is protected from wind stress and exposed to only weak solar radiation due to low levels of thermal expansivity (Farmer 1975, Matthews and Heaney 1987). As a consequence of these extremely low energy levels, under-ice bio-physical processes have been long ignored by aquatic research. Recently, Mironov et al (2002) and Jonas et al (2003) quantified the importance of radiatively-driven convection in ice-covered lakes (Figure 2). This remarkable phenomenon can be observed in nearly any ice-covered freshwater body after snow disappeared from the ice surface, and the solar radiation penetrating through the ice warms the underlying water. At that time, the current meters capable to register low velocities (with order of magnitude 1 mm/s) were not available. Thus, we are still experiencing a lack of understanding on the spatial and temporal dynamics of those convective currents. Also, not much attention was paid so far to the effect of water transparency on the development of under-ice convection. And, finally, the phenomenon has never been studied in Lake Ladoga.

Although, the purely physical drivers of the under-ice convection is understood, we never addressed the implication of the under-ice ecological processes. Today, the challenge is interdisciplinary and we aim at quantifying the role of under-ice convection for the early phytoplankton growth. Under-ice convection has been found to trigger early growth of phytoplankton (Vehmaa and Salonen 2009), as the convecting thermals mix deeper-laying nutrients close to the ice-cover. Vertical velocities associated with recirculating thermal plumes during under-ice convection are thought to be strong enough to overcome the settling velocity of non-motile phytoplankton and to keep them together with the nutrients in the light-flushed layer just below the ice-cover. In Lake Ladoga, the diatoms may comprise about 60% of the spring phytoplankton bloom (Petrova and Terzhevik 1992). As this species is non-motile, its location within a water column is controlled either by Stokes settling or by well pronounced updraught velocities. The latter are typical for the radiatively-driven convection.

Besides the academic interest on why many lakes (such as Lake Baikal) have such an enormous under-ice biological productivity, the phenomenon is also of very practical relevance. In many shallow lakes (such as several ten-thousands in the north of Canada, Russia and USA) the oxygen under the ice starts to fade away at the end of the ice-cover and, therefore, the under-ice plankton growth prevents the fish-kills.

This study envisions extending previous successful Swiss-Russian collaborations in under-ice dynamics. The proposed field measurements will allow a more defined characterization of
(i) the radiative transfer responsible for the onset of under-ice convection,
(ii) the vertical velocities induced by the recirculating cells and
(iii) the development of phytoplankton.

Figure 2: Vertical velocity component (positive upward, red) as measured by a coherent high-resolution ADCP over the full observed depth range in Soppensee (Jonas et al. 2003b).

2.2. Research plan

To test the importance of under-ice convection for phytoplankton growth and its implication for longer time scales our approach is based on field measurements and modelling. We briefly present the type of measurements that we will carry out in this project. The successful deployment of equipment in difficult conditions such as ice-covered lakes is guaranteed by the experience of the co-applicant from the Russian Academy of Science.

During field campaigns, the following measurements will be performed: vertical profiling of temperature, conductivity, dissolved oxygen, PAR within the water column, and velocity fields in the convective mixed layer at different locations in the lake (Figure 2). Measurements of solar radiation above and beneath the ice, determination of ice and snow thickness at all locations during the period of observations will be performed. Also, several thermistor chains can be deployed to evaluate spatial heterogeneity of the water temperature pattern. The field work can be divided into 2 categories. The first one includes intensive short field campaign of measurements in March 2015 and March 2016 when the ice is strong enough to safely support field work activities. The second one includes long-term under-ice moorings designed in collaboration with other subprojects.

Under Ice Field Campaign of Measurements

Time Schedule: From 13th to 28th March 2015 and in March 2016. The exact dates and lengths need to be adjusted according the development of the winter conditions.

In more detail, the tasks are as follows:

a) Measurements of radiative transfer
   Measurements will be carried out above the ice and under the ice at different depth in temporal coordination with the plankton profiling.
   - Spectral radiation measurements in the convective layer under the ice at various depth and locations with different loadings on the ice-cover (Ramses radiometers, Trios).
• Photosynthetically active radiation (PAR) within the water column (10 sensors, Alec Electronics).
• Meteorological stations including wind intensity and direction, net radiation, barometric pressure and temperature (MAWS201/ Vaisala)
• Solar radiation with pyranometers

b) Measurements of under-ice convection

We will use both temperature and velocity measurements in the first 5-10 m below the ice to investigate the convection dynamics.

- Velocity fields in the convective boundary layer (HR Aquadopp, Nortek)
- Long-time (duration : 3 months, sampling frequency 1 hour in bursting mode) velocity fields in the under-ice surface layer using upward looking high-resolution Acoustic Doppler Current Profiler (HR ADCP, RDI).
- Vertical (~0.1 m scale; Annex) mooring of high-resolution temperature logger (TR, RBR)
- Repeated CTD profiles in order to observe the build-up (daylight) and collapse (night) of the convective thermals; development of dissolved oxygen (CTD 75, Sea&Sun Technology)
- High resolution (mm-scale) upward looking temperature microstructure profile (SCAMP, PME)

c) Measurements of phytoplankton growth

We will use the Chlorophyll-a concentration as a proxy for the evolution of phytoplankton.

- Repeated CTD profiles including DO, fluorescence and transmissivity as a proxy for biomass (CTD 75, Sea&Sun Technology);
- Repeated nutrients measurements using Niskin bottles including, nitrogen, phosphorus and silica (phosphorus being the most important nutrients to be monitored), and comparison to the organic matter gross sedimentation under-ice
- Spectral radiation measurements (Ramses radiometers, Trios).

**Under Ice Mooring**

Time schedule: (1) From late March 2015 to early June 2015
(2) From mid October 2015 to early March 2016
(3) From late March 2016 to early June 2016

Under ice long-term mooring will be ultimately designed in collaboration with other projects. Our main objective is to measure the variability of convective mixing. Such mooring will provide the necessary statistics to evaluate the overall impact of under-ice convection and restratification processes on early biomass development:

- An upward looking ADCP mounted on a frame 10 m below the ice
- A chain of thermistors from 10 m below the ice to 2 m
- 2-3 DO loggers
- 10 PAR sensors

The mooring will be connected to the bottom with a releaser and the top of the mooring will be connected to a sub-surface buoy 2 m below surface to prevent any damage/loss when the ice is moving or melting.
Data Analysis and Modelling

This subproject will result in qualitative and quantitative description of the vertical structure of water temperature and velocity fields at the observational sites, and will provide insight into the nature of physical processes that govern the evolution of these fields. One of the main scopes will be to evaluate ability of the updraught convection velocities to restrain the phytoplankton cells within the Convective Boundary Layer.

In a second integration step, data from nutrients and light profiles will be integrated in a hydrodynamic model to describe the development of the phytoplankton under the ice which will be compared to the turbidity, absorption and chlorophyll profiles in order to quantify the biomass development.

The field measurements will provide the necessary data to develop a simple model that will examine the contribution of nutrient availability, light and physical forcing to the phytoplankton development.

2.3. Expected Results

The research objective of this subproject is to provide a simple model of under-ice phytoplankton growth as a function of nutrient availability, light and physical forcing and this, in close collaborations with other projects from "Lake Ladoga: life under ice".

Temporal and, if several ADCPs are available and at least 2-3 thermistor chains are deployed, spatial dynamics of convective velocities will be quantitatively described; the effect of convection on the phytoplankton development under ice will be quantitatively estimated. Also, it is planned to evaluate whether the shadowing effect of developing planktonic species may depress the convective boundary layer deepening.

2.4. Annex

a) Field Measurements (Design)

Figure 3: Illustration of short and long time moorings. A first hole will be drilled for short / long time moorings and four other holes surrounding the main hole will be used for repeated profiles. The main interest of having four holes in such low turbulence condition is to not record the perturbation from an earlier profile by moving to another hole after each profile.
Figure 4: Sketch of the long-term mooring

Figure 5: Sketch of the short-term mooring during fieldwork in March.

b) Timetable

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3. **Mapping convection cells using Automatic Underwater Vehicles**

*Dr. Alexander Bahr, Dr. Felix Schill and Prof. Alcherio Martinoli, DISAL laboratory, EPFL*

3.1. **Background**

When measuring water parameters under ice, the water volume available to limnologists for sampling is usually limited to the narrow water column below the bore hole. Of particular interest at Lake Ladoga is the slow convection of water in winter conditions, which is easily disturbed by activity on the ice and in the water. Oceanographic expeditions in the Arctic and Antarctic have used submersible robots, known as Autonomous Underwater Vehicles (AUVs), to extend the measurement range under the ice. However, these are usually large vehicles which would be difficult to deploy on a lake and would disturb the water with their movements, and due to their cost and complexity they are generally not used in limnology.

3.2. **Research program**

**Summary**

In order to extend the reach beyond the vertical column beneath the hole, we propose to release a small Autonomous Underwater Vehicle under the ice to collect sensor data in the volume around the hole, or along a transect between two holes. The AUV will be outfitted with suite of sensors which has been selected according to the needs of the physical and biological limnologists, measuring temperature, conductivity, dissolved oxygen, pH/ORP, chlorophyll-a, phycocyanin and turbidity.

Our AUV is a novel platform which is particularly well suited for this application. It is very small (70cm overall length) which facilitates deployment through the ice, and minimizes turbulent disturbances while moving through the water. To our knowledge, it is the smallest field-deployable AUV to date. Equipped with 5 thrusters, it is also capable to navigate at a very low speed (10cm/s) while precisely maintaining its depth and attitude, which is important for micro-scale measurements.

We plan to release the AUV into a bore hole, with an acoustic pinger lowered into the same hole as a reference beacon for navigation and homing. The AUV will be programmed to travel in a circular or grid pattern around the hole at multiple depths, based on input from the project partners and analysis of collected results. We will carry out development and adaptation of the AUV’s acoustic sensing system to enable robust bearing estimation from the AUV to the pinger and enable the AUV to perform robust navigation and homing back to the bore hole.

**WP1 – Customization of AUV for under-ice operation**

Operating under the ice imposes additional constraints compared to regular operation in open waters. The main challenge is reliable navigation and accurate homing to the bore hole. Normally an AUV can return to the surface to get a GPS fix to improve navigation accuracy, and if any unforeseen events happen – this is not possible below ice. To address this issue, we are developing an acoustic homing system, consisting of an acoustic transmitter to be lowered into the borehole, and a hydrophone array with signal processing hardware to be integrated into the AUV. By measuring the relative bearing to the transmitter, the AUV will be able to find back to the borehole at the end of the mission. Additionally, the bearing information can be used to improve positioning accuracy. Furthermore, the AUV’s navigation and emergency behaviours have to be adapted accordingly. The necessary adaptations and developments will be carried out starting September 2014 in parallel with other ongoing development work. Initial tests will be carried out in controlled environments (test tanks, pools) and in Lake Geneva prior to the March 2015 field trip.
**WP2 – Sensor integration**

As the sensor payload for the AUV, the EXO2 Sonde system from YSI was chosen with sensor modules for temperature, conductivity, dissolved oxygen, pH/ORP, chlorophyll-a, phycocyanin and turbidity, based on recommendations from the project partners at the EPFL Limnology Center (APHYS-EPFL) and Institut F-A Forel (UNIGE). We already contacted YSI and received confirmation that they can provide us with an OEM version of their sonde that we can integrate into our AUV, and we prepared technical drawings and interface specifications based on their input and a sample unit that was temporarily provided. For the final system integration, we will purchase one sensor unit from YSI as outlined in the project budget as soon as the funding is available. Integration tasks are the machining of bulkhead adapter plates, electrical interfacing and signal translation electronics, and software to configure the sonde and log data. Initial tests will be carried out with calibration fluids in the lab, and in Lake Geneva.

**WP3 – AUV deployment at Lake Ladoga (March 2015)**

The goal of the AUV deployments is to explore the horizontal dimension of under-ice convection cells. The robot will be programmed to perform a horizontal trajectory at constant depth radially out from the bore hole for a distance of 50-100 meters, perform a turn and follow an arc around the hole at constant radius for 5-10 meters, and return to the bore hole in a straight line. By including an arc segment, the AUV takes a different route back to avoid measuring in previously disturbed water. This manoeuvre can be repeated at different depths (e.g. in 1 meter increments), and in different initial headings. The most relevant depth for convection cells is between 1 and 10 meters below the ice.

The experiments will be carried out by Dr. Alexander Bahr and Dr. Felix Schill. We will require a bore hole of at least 1m diameter to deploy and retrieve the AUV, and to lower an acoustic transmitter as the homing beacon. If possible, a live camera feed from the hole under the ice would be helpful to supervise the AUV and guide it on the last few meters back into the hole.

During dives (in particular for vehicle retrieval) we need exclusive access to the bore hole to avoid getting tangled in other equipment or disturbing other experiments. We may also require temporary measures to reduce acoustic noise if it interferes with the homing system (e.g. noise from other underwater acoustic modems or equipment, generators, etc.). To reduce risk, we will verify the noise levels and performance of the homing system prior to each dive. If operation with a single homing beacon is too risky, we propose an alternative plan using two boreholes, where we send the AUV from one hole to the other. This way it is heading towards a beacon at all times, and it allows us to verify that it has a solid fix on the beacon before releasing it.

Data acquired during each dive will be made available to the research partners for analysis. If time permits, based on their feedback it may be possible to adapt mission profiles on following dives to potentially improve data quality and capture points of interest.

### 3.3. Expected results

The measurements obtained with the AUV during these runs will allow us to measure small-scale physical processes in Lake Ladoga in two- to three-dimensional structures, such as shear- and thermal-induced turbulence, patchiness of properties, micro-stratification and submesoscale lateral structures. In addition to the small-scale physical characterization of the water column, the quantification of the small-scale structuring of phytoplankton diversity is a clear focus of the project. This part of the project will enrich and augment the data sets collected in other experiments by adding the horizontal dimension. From the robotics point of view, this experiment would provide a high-impact case study for using very small AUVs for environmental science. We expect a number of high-impact publications in the field of robotics on the overall AUV system, navigation algorithms, acoustic homing under ice, and deployment in real-world conditions.
3.4. **Risks and mitigation**

As the AUV used in this part of the project is a new development with a number of novel components that are the result of prior and ongoing research, there are some risks compared to using off-the-shelf commercial hardware. The biggest risk is a potential loss of the vehicle, which cannot be completely avoided even with long-proven commercial models. In particular, the under-ice environment poses additional challenges on the navigation and complicates recovery, and is something that we cannot easily test before arriving at Lake Ladoga. To minimise these risks, we will first carry out tests with the vehicle on a tether to verify the performance of the acoustic homing system and navigation accuracy, and we will develop multiple recovery strategies based on local conditions and experiences. Based on these initial tests we will adjust the mission profile before carrying out autonomous missions. If, due to unforeseen circumstances, autonomous operation is deemed too risky, we will attempt to collect data by using a tether to the vehicle (either a passive recovery line, or a thin cable to additionally provide telemetry). We will also consider manually controlling the vehicle using VLF radio through the ice, for a part of the mission (e.g. the final meters to the recovery hole) or the entire mission. Our priority is to collect as much data as possible while minimising the risk of loss of the AUV. There is a residual risk that we will collect less data than planned.
4. **Impact of climate warming on phytoplankton distribution and diversity of Lake Ladoga**

*Prof. Bastiaan W. Ibelings and Prof Christel Hassler, Institut F-A Forel, Université de Genève, Geneva, Switzerland*

*Dr. N.M. Kalinkina and Dr. P. Lozovic – Institute of Northern Water Problems, Karelian Research Centre, Russian Academy of Sciences, Petrozavodsk, Russia*

### 4.1. Background

Lakes act as sentinels of change and are among the ecosystems with the strongest response to climate warming (Sommer et al. 2012). The dominant effect of climate warming is an increase in the physical stability of the water column, so that for instance Lake Zurich (Switzerland) is now ca. 25 % more stable than 25 years ago (Pomati et al. 2012). The consequences of these shifts in the balance between mixing vs. stability on lake ecosystems are manifold. Pomati et al (2012) demonstrated that the increase in physical water column stability over the last 3 decades in Lake Zurich resulted in a strong increase in the variability in the concentration of nutrients like phosphorous with depth. They hypothesised that this stronger heterogeneity in the availability of key phytoplankton nutrients allowed more phytoplankton species to coexist than in a homogenous lake water column. The authors furthermore hypothesised that this enhanced opportunity for coexistence could then explain the strong accrual of phytoplankton biodiversity in Lake Zurich since the 1970s. Pomati et al (2012) concluded that phytoplankton communities at different depths will become more dissimilar as a consequence of climate warming.

In a follow up paper the development of phytoplankton at different depths in Lake Zurich was studied during an intensive sampling campaign during the build-up of the spring phytoplankton bloom in 2010 (Pomati et al. 2013). Samples were taken several times per week at various depths and the phytoplankton was analysed using flow cytometry as well as microscopy, instruments which give information on the functional (size, shape, type of pigment, etc) and taxonomic (species, genera, families etc) diversity. For this spring period the same hypothesis – as outlined above for long term change in Lake Zurich, linking lake heterogeneity to biodiversity – was applied over much shorter time scales (days to weeks rather than years to decades).

Thus we hypothesise that when the physical conditions in the lake result in enhanced water column stability a heterogeneous system will develop, allowing phytoplankton communities at different depths to evolve in different directions. Competition between species will be local (per depth) – rather than global (water column as a whole), overall resulting in a more biodiverse phytoplankton community. Vice versa periods of low water column stability / well mixed conditions will result in homogenous conditions and an erosion of the phytoplankton diversity.

Light, in addition of nutrients, also represents a key resource for the growth of phytoplankton and the distribution of ecological niche within the water column. Here the relationship between in-situ light and phytoplankton biodiversity will also be investigated. Light we be measured using sensors deployed in situ or sensor measuring light intensity at the surface correlated with Secchi measurements. In situ light will be related to photo-physiological status of freshly collected phytoplankton using fast repetitive fluorimetry. This technique allows the measurement of key physiological parameters used to indirectly measure the degree of phytoplankton photosynthetic health (e.g., maximum quantum yield, Fv/Fm), as well as other important photosynthetic parameters. These include efficiently of light capture, electron transfer rate used to generate cellular energy associated with light reactions. In addition plasticity to variability of light variation such as expected to be encountered in the mixed layer, and recovery to excessive light exposure can be measured. Finally this technology will be applied to estimate primary productivity in situ – a key reaction to establish the biological carbon pump and the lake carbon budget.
Despite the fact that almost all water bodies in Russia are covered with ice in the winter, investigations of the structure and functioning of ecosystems under ice are scarce and fragmentary. In Karelia, lakes can be covered with ice from mid-November to mid-May (Efremova and Pal’shin 2011). Thus, we know little about the life of aquatic organisms during seven months of the year. In the past it was assumed that the algae community is dormant in winter and therefore studies during this period are not necessary. However, in marine system, despite extremely low light intensity, a thick mat of diatoms has been reported on the underneath ice cover at the interface with water. Due to the lack of data on the functioning of the algae population in winter, global theoretical concepts concerning the analysis of the production potential of reservoirs are difficult.

Marine ice is extremely rich in nutrients with concentrations from 10 to 1000-fold greater than surrounding water; ice can thus represent a key source to fuel phytoplankton bloom (and grazer) at the onset of melting. We expect that in early spring (during ice melting and break up) a maximum of primary producers and consumers (living closely below the ice) will be a characteristic trait of the large lakes of Europe. This feature is similar with perennial ice-covered lakes in polar regions (Lizotte et al. 1996). In these lakes, diatoms have historically been considered to be the primary members in the spring population (April–May) and form an important fraction of the phytoplankton primary production (Kirillin et al. 2009, Vehmaa and Salonen 2009). The present knowledge requires detailed (precise) investigations of the winter regime of hydro-physical processes, and the lake snow and ice regime with biota in different lakes in order to understand the basic mechanism of supporting communities functioning. In addition we will complement these analyses with nutrients (major nutrient: silicic acid, nitrogen and phosphorus; micronutrient: iron, zinc, cobalt) and organic matter to establish the seasonal change in physical, chemical and ecological conditions which may affect phytoplankton distribution in lake Ladoga.

4.2. Research program

The proposed work for Lake Ladoga would be organized around the observations and hypotheses outlined above for Lake Zurich. What is needed are (i) detailed observations at sufficiently high frequency- and sufficiently small depth sampling intervals on the parameters that can affect phytoplankton distribution. This include (i) the mixing processes and resulting physical structure of the water column, (ii) key nutrients (for instance daily sampling at one meter intervals within the euphotic zone), (iii) light distribution in-situ complemented with photo-physiological measurement. This information need to be coupled with analysis for the distribution of phytoplankton, characterized both on functional traits and species diversity. We propose here to use two parameters to measured phytoplankton biomass: chlorophyll a that is commonly used and POC in order to help deriving the role of phytoplankton on the lake carbon budget. In addition, organic matter – an important vehicle for nutrients and a tracer for terregenous input will be analysed.

Moreover Lake Ladoga offers the opportunity to make an extremely interesting comparison between mixing and the resulting phytoplankton distribution / diversity under winter and summer conditions in the lake. Convection under the ice (Vehmaa and Salonen, 2009) by heating through the sun or convection in summer e.g. by night time cooling would set up different mixing regimes, and when studied in detail could yield very interesting data on how physical structure controls phytoplankton diversity with depth and overall lake biodiversity. The knowledge gained in these short term, intensive campaigns, could even be used to better understand and predict the long term effects of climate warming on phytoplankton in lakes.

4.3. Expected results

- A direct comparison between the physical structure of Lake Ladoga in winter (under the ice) and in summer; importance of convectional mixing under the ice to keep phytoplankton (in particular dominant large and dense diatoms) in suspension (McKay et al., 2011).
• Detailed insight into how dynamics in the physical structure in winter and in summer determines vertical heterogeneity in nutrient availability with depth.

• Detailed insight into how phytoplankton communities at different depths develop in response to the dynamics in lake physics (mixing and light) and chemistry (nutrients), both in winter and summer. A direct comparison of phytoplankton diversity at functional and taxonomic level as a function of depth. The winter studies will teach us much on the under studied role of phytoplankton under ice (cryophyton).

• In addition detailed studies of (primary) productivity will be made, including chlorophyll levels, rates of photosynthesis and assimilation numbers. The timing of winter spring and summer blooms will be assessed and linked to local environmental conditions (in winter for in particular thickness of ice and snow cover).

• Lessons for the expected impact of climate warming – via physics and nutrients – on phytoplankton abundance and biodiversity as well as their productivity of lakes in different seasons of the year.

4.4. Detailed research plan

The sampling will take place during five campaigns (13 - 30 March 2015, 28 May – 06 June 2015, October 2015, March 2016 and June 2016). The personnel will involve: Dr. N.M. Kalinkina and Dr. P. Lozovic, Prof. Bastiaan Ibelings, Prof. Christel Hassler, Marie-Caroline Tiffay (assistant on the project in 2015), Justin Brookes (scientist on sabbatical leave in second half 2015) and MUSE Master students (2016). On each sampling trip a minimum of two, maximum of three of the above will be present (from Geneva side) in addition to the Russian counterparts.

Methods for sampling and analysis

The phytoplankton studies on Lake Ladoga can be subdivided into 3 parts:

1. Vertical distribution of phytoplankton in response to physical mixing processes and physico-chemical heterogeneity in the lake environment
2. Photophysiology of phytoplankton in response to resource availability (nutrients and light)
3. Sedimentation velocities of phytoplankton (to match with updraught convection velocities)

We estimate that almost all analyses can be performed in Russia, except for flow cytometry, micronutrients and POC where the fixed, acidified and frozen samples need to be returned to Switzerland (CH). For microscopic analyses, spectrophotometric analyses (Chl a, macronutrients) we need to discuss with the Russian partners.

PART 1: Vertical distribution phytoplankton

The following biotic and abiotic parameters will be needed (measured unless covered by others):

• Biotic:
  - Phytoplankton abundance (numbers/L) and biomass (µg/L)
  - Microzooplankton and mesozooplankton (numbers/L) and biomass (µg/L)

• Abiotic:
  - Vertical profiles with CTD equipped with multi-sensors: Thermistor data (°C), Chl fluorescence, Dissolved Oxygen (DO: mg/L), Photosynthetically active radiation (PAR) and pH
  - Secchi disk (m) depth
  - Chlorophyll a (µg/L)
  - Total Phosphorus (TP), Soluble Reactive Phosphorus (SRP in mg/L PO₄³⁻-P), Total Nitrogen (TN), Nitrate (mg/L NO₃⁻-N), and Silicic acid (mg/L, Si)

• Meteorological: Wind speed, Air Temperature (°C) and Precipitation (daily mm per year)

Field Measurements and Data Recording
The discrete depths of sampling are to be adjusted according to the fluorescence profile or Secchi depth on each sampling occasion. Sampling will be carried out at six discrete sampling depths throughout the water column. The three main sampling depths will be determined in the following way:

- **Depth 1:** Subsurface sample.
- **Depth 2:** The deep chlorophyll maximum (DCM) as determined by carrying out an initial profile using a Chl fluorometer at 0.5 m intervals. Sometimes a DCM may not be detectable. In this case the depth of sampling can be determined as 1 times the Secchi depth.
- **Depth 3:** Just below the photic zone, as indicated by 2.5 times the Secchi depth (or when available 1% of surface PAR)
- The sixth and deepest sampling point will always be at substantial depth, i.e. well below the euphotic zone.
- The last two depth will be evenly spaced to fill in the gaps between depths 1, 2 and 3.

Sampling volume should be determined according to expertise of local field crew. Samples for water parameters, phytoplankton, microzooplankton and microbial plankton will be taken from each of the three main depths using a Niskin bottle. In addition, an integrated water sample of the full photic zone (max depth: 2.5 X Secchi depth) for both mesozooplankton and phytoplankton.

The protocol for preservation and preparation of each parameter is outlined below:

(i) **Chlorophyll a**
Chlorophyll-a samples should be collected from each of the six depths. Whenever possible, sample processing should be done in subdued light, out of direct sunlight. Water can be filtered in the field or in the laboratory. Pigment degradation is reduced by filtering the water immediately after collection but sample need to be snap frozen.

(ii) **Nutrients**
Samples for dissolved (SRP, Si and NO3) and total nutrient (TP and TN) should be collected from each of the three main depths and transferred to two separate 200 ml HDPE bottle.

(iii) **Phytoplankton and microzooplankton**
Phytoplankton and microzooplankton (broadly the protistan dominated <200 µm size fraction) will be collected from the six sampling depths on each sampling occasion (using a Niskin bottle. In addition, one net tow of the full depth of the photic zone (2.5 X Secchi depth) should be collected using a phytoplankton net with mesh size of 20 µm. Prior to use, carefully clean and thoroughly rinse the interior of the net.

(iv) **Zooplankton**
Mesozooplankton will be collected using a vertical tow net (64 µm mesh size) with a collection bucket attached at the end. A net tow of the full depth of the photic zone (2.5 X Secchi depth) will be used to collect mesozooplankton. Prior to use, carefully clean and thoroughly rinse the interior of the net.

(v) **Functional phytoplankton diversity (flowcytometer)**
Samples should be collected from six discreet depths as before.

**PART 2: Photophysiology, organic matter and micro-nutrients**
These analyses, complement PART 1 and the sub-project on the carbon cycling. The following parameters will be collected at the 6 sampling depths. The methodology and equipment associated with the measurement of each parameter is shortly presented.

(i) **POC – Particulate Organic Carbon**
1L of water is filtered on pre-combusted glass fiber (GF/F) filters. To avoid contamination, filtration is made in a laminar flow cabinet. Filters will be prepared in CH and individually wrapped in alu foil prior pre-combustion. The foil is reused to wrap the filter which will be stored frozen until further treatments. Analyses need to be discussed as the University of Geneva does not have the appropriate facility.

(ii) **Coloured Dissolved Organic Matter - CDOM**
10 mL of water is analysed in triplicate using a fluorimeter (Turner Lab Trilogy) on site. The whole profile and MiliQ blanks are run using the same borosilicate tube to avoid variability. The fluorimeter will be calibrated in CH prior and after each expedition using Suwanne River Fulvic Acid (IHSS, SRFA, std II). These analyses will complement the DOC analyses and will be used to follow seasonal terregenous input.

iii) Dissolved Trace Elements
Dissolved trace elements will be sampled in acid washed HDPE bottles, filtered using a pre-washed 0.2 micron filters using PP pre-washed syringes in the laminar flow cabinet. Samples will be collected in 50 mL clean HDPE bottles, triples bags and kept at room temperature, and transported to CH. Samples will then be acidified using quartz distilled HCl and let to settle 3 months prior analysis by Inductive Coupled Plasma Mass Spectrometry at the University of Geneva. Because work with trace metal is easily prone to contamination, personnel will be trained at our Institute and involved in the preparation of equipment prior each field trip.

During winter – snow and ice layer in contact with water will be sampled to evaluate the contribution of the ice as a source of nutrients and organic matter – a key step to understand how ice melting can fuel phytoplankton bloom. Ideally to do so, a small ice corer made in non-contaminating material (aluminium, titanium or clean inox) would be needed. Maybe this should be discussed further to see what would be available in Russia (or CH). Different layer or ice could be cut and let to melt in clean Tupperware prior to be analysed on site or sampled for further analyses.

iv) Photo-physiology
Photo-physiological analyses will be done using a Chelsea FastTrack Fast Repetitive Rate Fluorometer (FRRF). This equipment is costly and fragile. An extensive standard operating procedure has been written and dedicated training will be given at our Institute.

For each of the 3 depths in the euphotic zone, 100 mL of water will be collected in a dark HDPE bottle and gently concentrated using a hand pump and a 50 mL pipette down to 10 mL. The concentrate of phytoplankton as well as the filtrate are then collected in 10 mL tubes and allow sitting in the dark for 1h prior to analysis. This time is required to insure that all photosystems (II and I) are empty and pigments are not excited.

Analysis include an optimisation and a blank for each sample which take approximately 10 min, then an automated 1h15 series of analysis is made. During storage and analysis, temperature should be kept as close as possible to in-situ temperature using cooler, water bath of the system and ice pack. Sample handling has to be done at low or dim light only. During automated analyses, samples for Chl a, POC, CDOM and trace elements can be processed. Such analyses are routinely made on Lake Geneva in our lab.

5. Carbon cycling and CO₂ dynamics in ice-covered Lake Ladoga

Dr. Natacha Pasche from Limnology Center, EPFL, Dr. Carsten Schubert and Dr. Beat Müller from Eawag, Dr. Hilmar Hofmann from the University of Konstanz and, and Dr. Sebastian Sobek from Uppsala
University, Sweden
Dr. Irina Iofina from Institute of Limnology RAS, St-Petersburg, and Dr. Natalja Belkina, NWPI KRC RAS, Petrozavodsk, Russia

5.1. Objectives and tasks
The objective of this project is to investigate carbon cycling and carbon dioxide (CO₂) dynamics during the ice-covered period. The hypothesis is that CO₂ accumulates throughout the ice-covered period, mainly due to microbial respiration of allochthonous dissolved organic carbon (DOC).

For this purpose, the following tasks will be performed:
1. Determine CO$_2$ dynamics and evasion to the atmosphere by in-situ measurements of pCO$_2$ concentrations in surface and bottom water throughout the ice-covered period and during ice thaw.
2. Determine methane (CH$_4$) and CO$_2$ fluxes at the sediment-water interface by measuring CH$_4$ and CO$_2$ concentrations within the sediment.
3. Quantify carbon cycling during the winter period, by measuring gross and net sedimentation of particulate organic carbon (POC) and concentration profiles of DOC, CO$_2$, CH$_4$ and dissolved inorganic carbon (DIC).

Respiration rates from bacterioplankton within the water column will be estimated from a mass balance between internal CO$_2$ accumulation and CO$_2$ fluxes from the sediment (Figure 8). Due to the large size of the lake and low water flow during winter, CO$_2$ inputs from surface and groundwater will be neglected.

![Figure 8: schematic view of carbon fluxes investigated during this study](image)

5.2. Background and justification

Substantial evidence has shown that a majority of lakes are net sources of CO$_2$ to the atmosphere (Cole et al. 1994). Particularly large lakes were shown to contribute most to CO$_2$ emissions to the atmosphere (Raymond et al. 2013). To emit CO$_2$, the aquatic system needs to mineralize more carbon than is fixed by primary production. In boreal lakes, respiration is usually more important than production because of the large input of humic substances from their catchment. These humic substances have two effects on primary production. First, their light shading limits phytoplankton growth. Secondly, aquatic bacteria can use humic substances to some degree as a substrate for growth, and as a result produce CO$_2$ through respiration. CO$_2$ can also be injected into lakes via surface water and groundwater inflows that are especially relevant for small boreal lakes.

Carbon dioxide emissions from boreal lakes have been mostly studied during the open-water period, setting emissions to zero during the ice-covered period, or assuming constant accumulation rates during ice-cover (Cole et al. 2007, Raymond et al. 2013, Butman and Raymond 2011). However, recent winter studies have identified CO$_2$ accumulation within the water column and a peak of CO$_2$ emission during the ice melting period (Karlsson et al. 2013). Unfortunately, such investigations never took place in a large lake.

This project offers the unique opportunity to investigate the large Lake Ladoga that is covered by ice during 6 to 7 months. This lake respires more organic carbon than is fixed by primary production (Petrova et al. 2010), because a large proportion of humic substances are degraded within the water
column. However, CO₂ concentrations within the lake and emissions to the atmosphere were never measured. We hypothesize that during the ice-covered period the water column will remain oxic but a substantial accumulation of CO₂ occurs due to continued degradation of DOC under the ice.

5.3. Research program

**Activity 1 - profiles.** We will determine the evolution of CO₂, CH₄, DIC and DOC concentrations in the water column during three campaigns per year. Water samples will be taken at different depths throughout the water column. CO₂ will be measured using the headspace method with an infrared analyser (EGM-4 Environmental Gas Analyser) on site. Water samples for CH₄, DIC and DOC will be stored and analysed back in Eawag laboratories. In-situ pH will be measured using a CTD probe. In March 2015, a CO₂ profile will be measured using a Contros HydroC sensor in collaboration with the University of Konstanz.

**Activity 2 - mooring.** We will measure CO₂ concentrations at high-frequency by placing CO₂ sensors in surface and bottom water on a mooring throughout the ice-covered period. To determine monthly fluxes of POC below the epilimnion and above the sediment, two sequential sediment traps will be attached to the mooring. The collected material will be analysed for TOC and TIC.

**Activity 3 – sediment core.** CH₄ and CO₂ areal production rates (mg CH₄ m⁻² d⁻¹) from the sediment will be determined from sediment concentrations profiles according to Sollberger et al. (2013). Near the location of the mooring, four short sediment cores will be retrieved. Three cores will be used to measure CH₄ and CO₂ concentrations at different depths while the last core will be analysed for geochemical parameters (TOC, TIC, porosity, grain size).

**Activity 4 – dark respiration.** Respiration of DOC by bacterioplankton will be evaluated by monitoring CO₂ concentrations in dark gas-tight vials over 5 days. The microbial respiration will also be determined by a mass balance between the total CO₂ accumulated within the ice-covered period and the production rate from the sediment.

5.4. Detailed research program

Most measurements will take place in a single location in the deep part of Lake Ladoga.

**Fieldwork March 2015**

Profiles: Discrete profiles of CO₂, CH₄, DIC, and DOC will be measured by collecting 30 water samples throughout the water column. For DOC, water will be filtered through a pre-heated (400°C, 3 h) GF/F filter. The filtrate will be acidified to pH 3 to remove inorganic carbon, and stored cold and dark in gas tight vials. For DIC, water will be filled in gas-tight vials with minimum air contact, acidified below pH 3 and measured as CO₂ on a gas chromatograph. For CO₂ and CH₄ concentrations, water samples will be transferred to 120 ml glass vials and poisoned with cupric chloride (CuCl₂). These parameters will be analysed back at Eawag laboratories.

pCO₂ from water samples will be measured by headspace equilibration in the field. 20 ml of ambient air will be added as headspace gas to 120 ml air-tight vial. The vial will be shaken for 2 min. The gas phase will be extracted from the vial using a gas-tight syringe and pCO₂ will be determined on a portable gas analyser (EGM4). pCO₂ of ambient air used by equilibration will be measured at the laboratory site. pCO₂ in the water sample will be calculated via Henry’s constant after correction for atmospheric pressure and the added amount of CO₂ in the headspace gas.

CTD profiles will measure pH, Chl-a, oxygen, temperature, conductivity and turbidity. Further, a step-like profile of pCO₂ will be determined using a Contros HydroC CO₂ sensor in collaboration with Hilmar Hofmann from the University of Konstanz.

Mooring: We will set up a mooring with two Mini Pro CO₂ sensors, the upper one fixed at 2 m depth with a range of 0 to 5 000 ppm, and the lower one 3 m above the sediment with a range of 0 to 10 000
ppm. We will also install two sequential sediment traps 10 m below the surface and 3 m above the sediment collecting settling material with monthly resolution. This mooring will be deployed until the next campaign in May 2015. In collaboration with the physical project, parameters on this mooring will include currents, temperature and photo-synthetically active radiation (PAR). A meteorological station recording air temperature, wind speed, wind direction and solar radiation will be installed on the shore.

Sediment cores: four sediment core will be retrieved to measure CH$_4$ and CO$_2$ concentration profiles. Twelve sediment samples (2 ml) will be extracted between 0 and 16 cm through side-ports using plastic syringes. They will be transferred to 25 ml glass vials with 4 ml of 2.5% sodium hydroxide (NaOH) (Sobek et al. 2009). The vials will be immediately sealed with butyl-rubber stoppers, shaken, and stored upside down until analysis for CH$_4$ concentrations. For CO$_2$ fluxes, twelve sediment samples from different depths will be transferred to 25 ml glass vials with 4 ml saturated CuCl$_2$ solution. They will be immediately sealed, shaken and directly measured on site with the infrared EGM-4 Environmental Gas Analyzer.

Water column respiration of DOC: To experimentally verify dark respiration, DIC concentrations will be monitored in vials after seven days. Water samples from two different depths will be transferred simultaneously to five 120 ml gas-tight bottles and stored dark and cold. All samples will be equilibrated with air before incubation, so that the pCO$_2$ gets lower and allows to detect a change in DIC. Two bottles will be poisoned with CuCl$_2$ immediately after sampling. The other three vials will be incubated during 7 days. DIC concentrations will be analysed on site as described above. The respiration rates will be calculated from the start and end values, assuming a linear change in concentrations.

**Fieldwork in May 2015/2016**

Profiles: Discrete profiles of CO$_2$, CH$_4$, DIC, and DOC will be measured from 30 water samples collected throughout the water column. CTD profiles will also be recorded.

Mooring: The mooring will be retrieved. Data from CO$_2$ sensors and material from sediment traps will be collected.

**Fieldwork in October 2015**

Profiles: discrete profiles of CO$_2$, CH$_4$, DIC, and DOC will be measured from 30 water samples collected throughout the water column. CTD profiles will also be recorded.

Mooring: The mooring will be exposed for 5 months until March 2016.

**Fieldwork in March 2016**

This campaign will be similar to that of March 2015, except that no sediment cores will be taken and that the mooring will be retrieved and set again until May 2016. The activities might be adapted depending on the results obtained from the previous year.

**Laboratory analyses at Eawag**

Sediment cores and traps: Total carbon (TC) in sediment will be measured using a combustion CNS elemental analyser (VARIO Co and EuroVector Co). Total inorganic carbon (TIC) will be analysed as CO$_2$ by coulometry (UIC Coulometrics) after acidification with 3M hydrochloric acid (HCl). TOC will be calculated as the difference between TC and TIC.

CH$_4$ and CO$_2$ concentrations from water and sediment samples will be measured by a headspace (30 mL N$_2$) technique similar to that of McAullife (1971) at Eawag on a gas chromatograph (Agilent, 6890) equipped with a Carboxen 1010 column (30m, Supelco) using a flame ionization detector.

DOC and DIC in water samples will be measured at Eawag using a Total Organic Carbon Analyzer (Shimadzu TOC-V CPH).
5.5. Expected results

For the first time, this project will provide CO₂ concentrations within Lake Ladoga at high-temporal and spatial resolutions. We expect a build-up throughout the ice-covered period, with a potential consumption in the epilimnion during diatom blooms. The measured release of CO₂ during ice thawing and mixing will allow to quantify the contribution of an extremely large boreal lake to the global C budget.

Mineralization rates at the sediment-water interface will be quantified with two different approaches. We expect low CH₄ production rates in sediment because of the refractory organic matter from the catchment and low temperatures. Methane is probably oxidised at the sediment/water interface, so that only CO₂ diffuses in the water column. However, methane concentrations will be measured throughout the water column, as methane ebullition might allow a small accumulation near the ice-water interface.

We will also compare the contributions of the respiration in the sediment and in the water column. As DOC represents >90% of TOC in the water column, we expect that its respiration in the water column is mostly responsible for CO₂ accumulation throughout the ice-covered period.

We expect two peer-reviewed publications to result from the project: the first one on the dynamics of CO₂ concentrations and CO₂ evasion from Lake Ladoga, and the second one on the carbon cycling in Lake Ladoga during winter.

6. The significance of under-ice biological activities to Lake Ladoga trophic functioning

Dr. Emilie Lyautey, Dr. Marie-Elodie Perga and Dr. Victor Frossard, UMR CARTEL, Limniques/ Alpine Research Centre on Lake Food webs, INRA-Thonon-les-Bains.
Dr. Natalja Kalinkina, Northern Water Problems Institute KRC RAS, Petrozavodsk

6.1. Objectives and tasks

The objectives of this project is to investigate (1) microbial communities and activities under the ice, (2) their contribution to lake food web and metabolism under the ice, (3) their significance to the whole lake functioning and how this might change over climatic pressure.

For this purpose, the following tasks will be performed:

1. Determine the diversity, the abundance and the transcription rate of methanogens and methanotrophs prokaryotes in the sediment, the water column, and associated to the under-ice diatoms at the deepest part of the lake.
2. Identify the total and active microbial diversity of benthic and pelagic prokaryotes and photosynthetic eukaryotes,
3. Evaluate microbial contribution to zooplankton diet and the origin of carbon sustaining the food web under the ice.

6.2. Background and justification

In most temperate lakes in winter, environmental conditions are rather steady under the ice-cover and biological activities strongly hampered by low temperature and light limitation until thawing. In these lakes, the spring phytoplankton bloom begins shortly after ice off (when the last ice breakup before summer's open waters is observed) boosting all associated heterotrophic activities. In contrast, in Lake Ladoga such as in Lake Baikal, ice transparency allows light penetration as soon as late February, hence allowing convective mixing and diatom production under the ice. Therefore, in these lakes ice is essential for initiating and sustaining this bloom (Moore et al, 2009) which is essentially constituted of
endemic species. The under-ice spring bloom, because of its duration (3 months) and specific endemic composition, is expected to be of primary importance for top-consumers, up to large mammals (Moore et al, 2009) although under-ice food webs have been poorly studied so far. On the other hand, chemoheterotrophs (such as methanotrophs) have been shown to be significant producers for Alaskan lakes covered with ice (Heintz et al, 2010) and these methanotrophs can constitute a significant food source for metazoan consumers (Kankaala et al, 2006, Taipale et al 2007). With the evidences that methane production can be strongly correlated to photosynthesis in oxygenated waters (Tang et al, 2014) and that limnic vs. coastal organic particles in marine systems sustain different bacterial communities (Bižić-Ionescu et al, 2014), the peculiar hydrodynamic functioning of Lake Ladoga should provide interesting insights into microbial functioning. Hence, both diatoms under-ice production and the microbial chemo-heterotrophic biomass may sustain the secondary productivity of Lake Ladoga under the ice. Our primary objective is therefore to characterize these microbial communities and assess their relative contribution in sustaining the under-ice food web of Lake Ladoga.

Under-ice convective mixing yet occurs only during daylight, i.e. the lake thermal and consequent chemical (O2) vertical structuration varies on a daily basis, and so should biological activities and the availabilities of food sources. Our second objective is to evaluate whether biological activities and the strength of trophic links change on a daily basis due to the strong spatial and vertical heterogeneity of the water column under the ice.

Climate change could threaten the under-ice algal bloom in Lake Ladoga by reducing the duration of ice-cover and favouring open-waters spring blooms. These changes in the quality and quantity of food sources available for consumers may trigger strong changes in the food web structure and biological activities. Our last objective is to compare food webs and microbial activities during ice-covered time periods.

6.3. Research program

Activity 1. Methanotrophs and methanogens diversity and activity will be assessed based on functional genes markers (mcrA for methanogens and pmoA for methanotrophs) using real-time PCR and sequencing of DNA and mRNA. Analyses will be carried out at different depths in the water column and within the sediment. The importance of organic matter lost from the convective cells on microbial activities will be assessed based on material collected in sediment traps. Molecular (DNA and RNA) data will be analyzed relatively to methane / carbon dioxide production rates from WP5, and the activity potential from these communities will be assessed base on semi-potential fluxes estimation. The expected outcomes are the identification of total and active methane-cycling micro-organisms, the quantification of their abundance and transcription rates, the estimation of their actual and potential activities. All together this should allow to determine the contribution of methanotrophs and methanogens to methane production / consumption in Lake Ladoga.

Activity 2. Total and functional prokaryotes and unicellular eukaryotes diversity will be characterized based on the 16S-18S rRNA gene phylogenetic markers, using next generation sequencing approaches based on DNA (total) and rRNA (active) molecules for Archaeal, Bacterial and eukaryotic communities.

Activity 3. Contribution of micro-autotrophs and heterotrophs to metazoan secondary production will be tracked using fatty acid specific stable isotope analyses (Perga et al, 2013). The variability of such trophic interactions will be studied as much according to the temporal variability in vertical heterogeneity under ice (day/night for 5 days).

Activity 4: changes in food webs structure over time, using paleo-limnological records (cladoceran subfossil remains from sediment cores, as in Alric et al, 2013).
6.4. Detailed research plan

Under-ice campaign (March 2015/2016)

2 persons involved from CARTEL in 2015 and 4 in 2016: M. Perga and E. Lyautey or V. Frossard.

Water column samplings before and after daily settlement of convective mixing (in addition to probe vertical profiles, nutrient measurements and phytoplankton countings by Ibelings’s subproject) for 3 days:

1. 30 L pumped from the photic and aphotic zones (DNA, RNA, compound-specific stable isotope analyses). 2 L of water from each sample to be fixed with the same volume of RNAlater solution and to be filtrated rapidly (for DNA and RNA analyses). The remaining water samples (compound-specific stable isotope analyses) to be filtrated once back to the lab.

2. Zooplankton sampling over the water column (64 μm mesh size for isotopes and compound-specific isotopes). Sorting when back to the lab.

3. Benthos sampling with Eckman grab. Sorting when back to the lab.

Sediment samplings:

1. Three short cores (cladocerans, chironomids and methane-cycling communities, and activities-transcription and gaz flux incubations).

2. One core for DNA and RNA analyses, to be conditioned (sub sampled rapidly)

3. The others two for incubations (potential rates of methane production – complementary to WP5 methane areal production rates) and after incubation for cladocerans and chironomids communities.

6.5. Expected results

This project will allow to determine the contribution of micro-organisms to CO₂ and CH₄ cycling within Lake Ladoga. We expect the abundance and transcription activity of methanogens and methanotrophs to be correlated with bioavailable organic matter and measured CO₂ and CH₄ production rates (sub project 5 – carbon cycling). We also expect functional and total (present or active) microbial diversity to differ spatially: between convective cells area (under ice diatoms), the remaining water column and the sediment.

Vertical heterogeneity in the physical and chemical conditions of the water column is expected to affect the availability of the autotrophic and heterotrophic food sources to consumers, hence creating temporal and spatial niche partitioning. The trophic links are expected to be numerous but weak, resulting in diverse and complex food webs. Autotrophic microbes are expected to the main resource in euphotic, stratified water column (daytime under the ice or littoral stratified water column after break up) while heterotrophic microbes should dominate the diet and the carbon pathways during unstratified conditions (night time under the ice or unstratified water column after break up).
7. **Lake Ladoga Sediment Archives - Paleolimnology, paleoeclimatology and sedimentary microbial activity.**

Prof. Dmitry Subetto, Prof. Nikolay Filatov and Dr. Natalya Belkina from Institute of Northern Water Problems, Karelian Research Centre, Russian Academy of Sciences, Petrozavodsk, Russia  
Prof. Daniel Ariztegui from University of Geneva and Dr. Nathalie Dubois from Eawag

7.1. **Background**

Sediment archives make it possible to study long-term climate changes and early human impact, and to investigate the response of the aquatic system to these changes.

At the end of the Pleistocene, pre-Ladoga and pre-Onego were oligotrophic cold water bodies. Gradual climate warming in the early Holocene resulted in the development of mixed conifer and broadleaved forests vegetation in the lakes’ watershed. At this time, homogeneous clays with high biogenic concentrations were deposited in the deep parts of the lakes (Davidova and Subetto, 2000).

About 5 thousand years ago (Saarnisto et al. 1996, Subetto et al. 2009 and 2013), the isostatic rise in the Near-Ladoga region modified the hydrographic network. The flow of the Saimaa Lake system was redirected through the River Vuoksa to Lake Ladoga, increasing the inflow rate by approximately one third. The highest lake water level was reached about 2000 years ago. After a new threshold flow rate was established, the Lake Ladoga water level started to decline. The Neva River became the only outflow from Lake Ladoga to the Baltic Sea. The final shape of the Great European Lakes system was formed less than 2 thousand years ago, when Lake Ladoga’s water level attained its present day value of 4 - 5 m above the sea level. At that time, erosion processes intensified in the watershed, creating favourable conditions for natural and gradual lake ecosystem eutrophication processes.

In more recent times, the area north of Lake Ladoga and Onego, known as the Karelian Republic, witnessed drastic changes in its land use, which also impacted the lakes ecosystems. Finns used this territory in the northern part of Lake Ladoga intensively for arable field cultivation until World War II. After the war, the fields were mainly used as pasture by state farms without regular ploughing. Miettinen et al. (2005) investigated how changes in the agricultural intensity impacted the history of eutrophication and recovery in small lakes on the northern coast of Lake Ladoga.

7.2. **Research program**

Our plan is to recover sediment cores and sample lake bottom deposits. Sampling during the winter season is easier as we can work directly from the thick ice-cover, which allows us to be more precise when recovering the near bottom/sediment boundary layer for the analysis of the dynamics of pollution by micro pollutants and heavy metals.

The planned research program will sample lake bottom deposits along a transect from the shallow to the deep part of the lake. Such studies have never been conducted before on Lake Ladoga (Subetto 2009). These key sites will encompass different bathymetrical and environmental boundary conditions, in terms of topography, geology, depth and water circulation. These sites will represent both shallow and deep lacustrine systems with biogenic sediments including diatoms, chironomids, and pollen, which most sensitively document the lake-level status, temperature fluctuations, and limnological and vegetation changes in response to climate variability and human pressure.

The cores will be shared amongst Russian and Swiss partners, with multiple complementary analyses carried out in each country. The Russian partners will focus on the recent and long-term climate change, whereas the Swiss partners will focus on sedimentary microbial activity (Prof. Ariztegui) and paleo-environmental conditions and their relationship with anthropogenic activities in the catchment (Dr. Dubois).
7.3. Objectives

Reliable records of hydrological and climatological data are limited to the last 150 years. As a result, these instrumental data sets only allow the investigation of short-term climatic fluctuations and the lake’s ecosystem response to these variations. Sedimentary archives and paleo limnological data analysis on the other hand allow the investigation of long-term climatic changes. Our first objective is to determine the timing of physical and biological processes in order to establish a relationship with the external forcing conditions, and then to apply this knowledge to downcore climatic reconstructions.

Our second objective is to determine how changes in land-use have modified soils and altered the terrestrial material delivered to the lake. Whereas Miettinen et al. (2005) studied pollen and diatoms to reconstruct the lakes’ trophic levels, here we would assess early human impact, such as deforestation and ploughing, through the use of molecular indicators and the identification of microbial activity in the sediments. Specifically, we would determine the age of terrestrial biomarkers to estimate their residence time in soils, and see how it changed with the evolution of land-use. Analogously, variations in active microbial populations through time will be linked with the known land-use development (Haller et al. 2011).

Tasks:
- Data analysis of climate changes and hydro-meteorological regime of Lake Ladoga for last 150 years.
- Recover fresh gravity cores from the frozen lake surface.
- Split cores, describe and subsample for each partner.
- Analyse subsamples at respective laboratories.

7.4. Methods and Approach

A multi-proxy interdisciplinary approach will be applied, comprising traditional and innovative methods: sedimentary facies analysis, radioisotopic dating (age models), provenance analysis of detrital sediment components, the study of palaeoecological and climate signals in fossil bio-indicators (pollen, diatoms, chironomids), stable-isotope geochemistry of diatoms, uranium-series isotopes in the lake sediments, heavy metal pollution, organic biomarkers (GDGTs, leaf waxes), compound-specific isotopic determination ($\delta^{13}C$, $^{14}C$), DNA extractions in bulk sediments and genomic determinations.

Sedimentological features (lithofacies, granulometry, sediment structures) will provide clues for the modes of detrital sediment input. Detrital sediment compounds will be used to infer changes in riverine runoff (provenance signals) and to trace paleo-weathering conditions in the terrestrial hinterland (clay minerals). The distribution of major sediment compounds (biogenic silica, organic matter, siliciclastics, calcium carbonate) will allow insight into the intensity of biological productivity and the hydrological balance (Colman et al. 1995, Diekmann et al. 2004). The geochemical characterization of organic matter (C, N, S, carbon stable isotopes) will be used as an indicator of former lake-level fluctuations and ecological conditions, driven by lateral movements of the shorelines that control the balance between the supply of littoral plant materials and open-water algae. Fossil molecules derived from soils will be used to track the history of early human impacts, in particular the changes in agricultural practices in the lake watershed.

In addition, a detailed analysis of long-term observations (more than 150 years) of the hydrometeorological regime in the watershed will be carried out. Climatic data will be assembled and analyzed to reveal tendencies in climate change in the lake’s watershed.

The methods imply the application of conceptual and mathematical models (transfer functions) for the reconstruction of paleo-environmental variables. The outcomes will be compared and validated by experiments with general circulation models (GCM).
7.5. **Detailed research plan for the field campaigns:**

**March 2015:** NWPI: Dmitry Subetto, Natalya Belkina, Nikolay Filatov  
UNIGE, Eawag: Daniel Ariztegui, Nathalie Dubois

**March 2016:** NWPI: Dmitry Subetto, Natalya Belkina, Nikolay Filatov  
UNIGE, Eawag: Daniel Ariztegui, Nathalie Dubois

**May 2016:** NWPI: Dmitry Subetto, Natalya Belkina, Nikolay Filatov

**On the field:**

03.2015 - Coring from the ice.  
Location: To be defined (Depending on seismic & location for physical measurements)  
Short cores: Nb = 8  
For: CO₂ and C cycling (Natacha Pasche), Trophic functioning (Marie-Elodie Perga), sediment archives (Nikolay Filatov, Dmitry Subetto, Natalya Belkina, Daniel Ariztegui, Nathalie Dubois)

03.2016 – Coring from the ice.  
Location: To be defined (Depending on seismic & location for physical measurements)  
Longer cores. Nb = 3  
For: Trophic functioning (Marie-Elodie Perga), Sediment archives (Nikolay Filatov, Dmitry Subetto, Natalya Belkina, Daniel Ariztegui, Nathalie Dubois)

06.2016 – Coring from a Research Vessel  
Location: to be defined  
Short sediment cores Nb = 3  
For: sediment archives (Natalya Belkina)

**Special requirement on the field**

- Coring equipment (Gravity Corer, Uwitec Corer, PVC tubes, caps, tape, marker, tube-cutter)  
- GPS positioning system  
- Echosounder  
- Tripod  
- Opening core and/or extruding facilities to measure onsite microbial activity within the sediments  
- Winch

**Laboratory Analysis:**

The cores will be shared amongst Russian and Swiss partners, with complementary analyses carried out in each country. Results and data will be shared amongst participants.

**NWPI, Russia:**

- sedimentary facies analysis (lithofacies, granulometry, sediment structures)  
- provenance analysis of detrital sediment components (clay mineralogy)  
- major sediment compounds (biogenic silica, organic matter, siliciclastics, calcium carbonate)  
- geochemical characterization of organic matter (C, N, S, carbon stable isotopes)  
- pollen, diatoms, chironomids (palaeoecological and climate signals)  
- stable-isotope geochemistry of diatoms  
- uranium-series isotopes in the lake sediments  
- heavy metal pollution

**Switzerland:**

**Eawag:**

- radioisotopic dating (age models)  
- organic biomarkers (GDGTs, leaf waxes)
- compound-specific isotopic determination ($\delta^{13}$C, $^{14}$C)

*UniGE:*
- DNA extractions in bulk sediments and genomic determinations.
- ATP determination of living microbes in bulk sediments (to be done in the field)

## 7.6. Expected Results

The sedimentary records from Lake Ladoga will be studied by our consortium of experienced Russian and European palaeoclimatologists and limnogeologists. Synergy effects will be reached through joint efforts in interdisciplinary traditional and novel methodological approaches, the sharing of tasks at the different sites, and a final comprehensive synthesis of the results in the context of the natural and man-made variability and interconnections with the global climate system.

We expect to see correlations between the timing of physical and biological processes in Lake Ladoga and external forcing conditions. In particular we expect to observe changes in lake-level status and vegetation in response to climate variability and human pressure.

We expect to see changes in lake sediment that can be related to past land-use, in particular the drastic changes in the residence time of organic molecules within soils as land-use shifted from arable field cultivation to cattle pasture. This study could help to define a background state before anthropogenic impact started.

We expect fossil molecules derived from soils to track the history of changes in agricultural practices in the lake watershed. Analogously, we expect variations in active microbial populations through time to be linked with the known land-use development.

## 8. Multiscale multispectral remote sensing of Lake Ladoga using a combination of spaceborne, airborne and ground-based measurements

*Dr. Yosef Akhtman, Martin Rehak, Dragos Constantin, Prof. Bertrand Merminod, TOPO, EPFL*
*Prof. Nikolay Filatov from Northern Water Problems Institute*
*Dr. B. Ivanov from Arctic and Antarctic Research Institute*
*Dr. Anton Korosov, Nansen International Environments and Remote Sensing Center*

### 8.1. Background

Subject areas: Ice formation, its physical properties and structure and ice dynamics, the morphometric and thermal properties of snow, and the thickness and the texture of the ice.

Airborne remote sensing technologies provide some of the most effective methods for the exploration and study of the Earth surface (Campbell and Randolph, 2011). In particular, multispectral and hyperspectral spaceborne and airborne observations are widely used to study different natural and anthropogenic processes (Schaepman et al. 2009) including those pertaining to water bodies (Koponen et al. 2002). The recent technological advances that make remote sensing equipment ever more accessible have brought about a new surge in the interest towards the development of novel and powerful remote sensing methodologies. Of particular interest in this context is the emergence of multiscale analysis, where data from multiples sources: satellites, aircrafts and ground sampling measurements representing different spatial and temporal scales are correlated and jointly processed (Lausch et al. 2013).

As part of the first stage of the Leman-Baikal project, we have successfully developed and deployed a hyperspectral remote sensing platform, which was utilised to perform a range of limnological studies
over Lakes Geneva in Switzerland and Baikal in Russian Federation. The scientific objectives of the project included the analysis of hydrological processes, such as the runoff dynamics of both natural and anthropogenic origin, lake energy balance, and the study of processes pertaining to the land-water and air-water interfaces in lakes. The primarily results obtained so far are reported in Akhtman et al. (2014).

Against this background the current proposal intends to leverage and further extend the technological and scientific capabilities attained as part of the Leman-Baikal project. Specifically, we will adapt our system for deployment from a compact Unmanned Aircraft System (UAS). Multiple sensory payloads will be developed to address the corresponding scientific objectives during the winter campaigns. Specifically, the characteristics of energy and mass exchange processes between the atmosphere and the lake during the winter seasons will be investigated related to different conditions of stratification in the atmospheric surface layer (near the ice surface).

### 8.2. Objectives and tasks

The main goal of this research is to study the development of freshwater ice and its potential impacts on bio-physical and socio-economic systems of the lake.

The effects of freshwater ice on climate are most obvious at a regional scale, with the degree of influence depending on the magnitude, timing, location, duration of ice-cover and ice-free period, and lake size. It is important to investigate how the formation, growth, decay, and break-up of ice are influenced by climatic variables that control surface heat, energy and gas fluxes. Due to the large size of Lake Ladoga, it is expected that its effect will be important for a relatively large regional area.

### 8.3. Research Program

![High-resolution terrain mapping using a combination of airborne and spaceborne HSI, as well as spatio-spectral signature database](image)

The main principle of the research methodology is constituted by the concurrent acquisition of airborne wide-area and surface point-based data as illustrated in Figure 9. Specifically, we will utilise an Unmanned Aircraft System (UAS) in order to carry an airborne remote sensing platform.

*Activity 1 – Collection and analysis of historical ice and snow data.*
- Creation of a database using long-term observations: in the first stage of the project, historical data on the spatial and temporal variability of snow and ice-cover on the lake will be collected. The dynamics of the formation and the destruction of the ice-cover will be based on satellite observations.

- Details of the location and the dynamics of cracks, polynyas, leads, ridges, hummocks and ice drift will be investigated, based on data collected during many years of observation:

- Multi-annual observations of ice regime (microwave, SSMI/SMMR, 24 km, 1978 – 2012, AMSR-E 12 km, 2002 – 2012). Microwave remote sensing data from SSMI or SMMR sensors at 24 km spatial resolution and from AMSR-E at 12 km will be used for estimating ice concentration in Lake Ladoga. Maps of ice concentrations allow studying seasonal dynamics of lake freezing and assess inter-annual trends in changes of maximum ice area. Access to the raw L1B remote sensing data is free, software for calculation of ice concentration is also available for free.

- Seasonal dynamics of lake surface temperature (TIR, NOAA AVHRR 1981 - 2014 MODIS 2002 – 2014). Thermal infrared data from NOAA AVHRR or from MODIS/AQUA will be used for the calculation of lake water temperature with a 4 km spatial resolution. Average annual temperature and dynamics of water cooling will be studied for describing pre-freezing conditions, dynamics of the autumn thermal bar and assessing stratification of the lake. Access to L3 (mapped and binned data at 4 km) is free.

- Location and dynamics of cracks, polynyas, ridges and ice drift (SAR, Envisat 2002 – 2012, Radarsat2 2007 – 2014). High resolution (30 – 100 m) SAR data from Envisat/ASAR or Radarsat-1/2 will be used for estimating the roughness of lake water/lake ice and for the identification of small scale features: floats, polynyas, leads, ridges, hummocks, and cracks. Small scale dynamics of these features will be examined for studying elasto-viscous processes of ice. Radarsat and ASAR data is very expensive for commercial use (several thousands USD per frame). However, it is possible to obtain these data from ESA under the GMES program (even Radarsat-2 as a replacement of Envisat). Software for processing (visualization and geographical correction) is free.

Activity 2 – Development and deployment of a multispectral UAS remote sensing platform

A compact hyperspectral remote sensing platform will be developed in order to collect multispectral and hyperspectral observations of the ice surface from an UAS. The platform will be comprised of three cameras, auxiliary position and orientation sensors, as well as data recording equipment. The main instrument will be constituted by the Anyband 16-band VNIR mHSI sensor. In addition, the platform will include a high-resolution near-infrared (nIR) based on Ximea xiQ camera, as well as a thermal infrared sensor based on the FLIR Tau-2 TIR sensor. As an airborne carrier we will utilise the senseFly eBee mini-drone.

Activity 3 – Collection of data during two field campaigns.

Two field campaigns will be carried out in Lake Ladoga from the ice. This activity will result in a qualitative and quantitative description of the ice and snow characteristics, and the dynamics of ice fields.

Specifically during the winter phase of the field campaign on Lake Ladoga, the UAS-deployed hyperspectral and thermal remote sensing data will be systematically collected. The resultant data will allow us to monitor and analyse the dynamics of the ice movement and the energy flow at the ice-air interface. Additionally, the airborne remote sensing measurements will assist in precise georeferencing of all subsequent ground-based measurements and activities.

In addition to the airborne observations, during the winter phase of the project, the following ground-based measurements will be taken: physical parameters of ice and snow, investigations of near-boundary layers, chemical and biological parameters (suspended materials, CDOM and PAR within water column for details, see Section Biological studies).
Measurements of the parameters in atmospheric boundary layer above the lake: solar radiation above and below the ice, determination of ice and snow thickness and their physical properties at all locations during the period of observations.

**8.4. Expected Results**

1. A detailed methodology for UAS-based high-resolution hyperspectral and thermal remote sensing of ice surfaces.


3. Better understanding of the ice dynamics for a lake of this large scale is expected. The effect of ice and snow parameters on phytoplankton development under ice will be quantitatively estimated.

4. Accurate geolocation and mapping of sampling and measurement sites for all the research activities corresponding to the various work packages of the project.

**8.5. Detailed research plan for the field campaigns**

*Campaign in March 2015*

Hyperspectral and thermal aerial surveying – TOPO: Y. Akhtman and M. Rehak
Measurement: Hyperspectral and thermal aerial surveying, physical parameters. The localisation will be defined on site.
High-resolution hyperspectral maps: 500m flight altitude, 30km fanning flight trajectory
30 flights over a period of three weeks covering the total area of 300 square km. The surveyed area will be revisited three times in order to obtain ice movement dynamics.
Physical parameters: suspended materials, CDOM and PAR within water columns. Solar radiation above and under the ice.

*Campaign in March 2016*

Hyperspectral and thermal aerial surveying – TOPO: Y. Akhtman and M. Rehak
Measurement: Hyperspectral and thermal aerial surveying, physical parameters. The localisation will be defined on site.
High-resolution hyperspectral maps: 500m flight altitude, 30km fanning flight trajectory
30 flights over a period of three weeks covering the total area of 300 square km. The surveyed area will be revisited three times in order to obtain ice movement dynamics.
Physical parameters: suspended materials, CDOM and PAR within ice columns. Solar radiation above and under the ice.

The equipment in the field will include: fixed wing unmanned airborne system (senseFly eBee), rotary unmanned airborne system (topohex), VISNX hyperspectral imaging sensor and FLIR thermal imaging sensor

*Data Analysis*

The collected data will be analysed in order to obtain ice condition and ice-movement patterns. In particular the high-resolution hyperspectral and thermal data will be compared to the large-area, low-resolution satellite-based observations.
All collected data will be shared between Russian and Swiss collaborators. The Swiss partners (TOPO) will be primarily responsible for the collection of the high-resolution hyperspectral and thermal data using a small UAS.

**Russia, NWPI, AARI, NIERSC:**
- Collection and analysis of the available historical satellite and airborne data
- participation in the processing of the aerial hyperspectral and thermal imagery
- correlation between satellite, airborne and terrestrial data sources
- modelling of the dynamics based on the collected airborne data

**Switzerland, TOPO:**
- development of a UAS-based hyperspectral and thermal aerial surveying methodology over ice
- development of the data processing tool chain
- operations of the UAS

### 8.6. Expected outcomes

We expect to obtain a detailed map of the ice condition and movement patterns in specific regions of interest. Additionally, we expect to obtain a methodology for joint processing of spaceborne, airborne and terrestrial hyperspectral imagery.

## 9. Organization

### 9.1. Managing structure

We propose to have the following structure to manage this project.

Heads of the project: Dr. Frederik Paulsen, Prof. Philippe Gillet and Prof. Alfred Wüest

Coordination between Swiss and Russian partners: Michael Krasnoperov, Russia Consulate in Lausanne

Scientific coordinator for Swiss partners: Dr. Natacha Pasche, Limnology Center, EPFL.

Scientific coordinator for Russian partners: Prof. Nikolay Filatov, Northern Water Problems Institute.

Deputy coordinator for Russian partners: Dr. Arkady Terzhevik, Northern Water Problems Institute.

### 9.2. Logistics for fieldwork

We propose to have fieldwork before, after and during the ice-covered period. The aim of ice-free fieldwork is to determine conditions after and before the ice-covered period, and to set up moored instruments that will record conditions under the ice throughout the winter. A longer fieldwork will take place on the ice in March during two consecutive years. We propose the following partitioning:

1. On ice - March 2015: 15 days
2. After ice thaw - May 2015: 3 days (+ 4 days from Petrozavodsk to Lake Ladoga by boat)
3. Before freezing - October 2015: 3 days (+ 4 days from Petrozavodsk to Lake Ladoga by boat)
4. On ice - March 2016: 15 days
5. After ice thaw - May 2016: 3 days (+ 4 days from Petrozavodsk to Lake Ladoga by boat)

Days mentioned above are only for fieldwork and additional days are necessary to account for travelling. During the free-ice period, the research vessel “Ecolog” from NWPI will perform a lake wide survey. Key parameters will be measured before and after the ice-covered period, in order to link the winter studies to the open water conditions before and afterwards. It must be noted that a minimum of 2 days are required for Ecolog to drive from Petrozavodsk to the northern part of Lake Ladoga.

From the ice in March, campaigns will be organized similarly to North Polar studies from AARI. For this, tents will be installed above drilled ice holes. The research team will be transported to the site by snowmobile, hydroplane or helicopter, depending on ice conditions.
We propose two sites for observation:

1. Near the deepest part of the lake, not far away from Valaamo Island with a depth of about 100 m. Multidisciplinary winter studies of the lake were never realized so far in this part.

2. In the nearshore zone in the Northern part of the lake (close to Sortavala or Pitkaranta Cities), with a depth of 20 to 30 m. This is an important observation point to select a suitable site for drinking water intake.

All researchers will be staying in a hotel in Sortavala City in the North part of the lake. They will be transported by snowmobile, helicopters and hovercrafts to the field sites.

The table below shows the repartition of scientists between the five campaigns:

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10. **Budget**

The table below summarizes the total costs for each subprojects. The total budget for the entire project amounts to 1.20 mio CHF.

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11. **References**


