SOIL TEMPERATURE

AIM

To monitor the soil temperature at single or multiple depths over several years in order to provide long-term data on soil temperature change.

RATIONALE

Soil temperature influences and is influenced by biodiversity and atmospheric processes. Understanding the soil temperature profile of a site will provide information on the impacts of climate change and, in turn, its influence through soil temperature shifts, on biodiversity in Canadian ecosystems.

BACKGROUND

Soil temperature monitoring is the recording of the temperature of soil at specific levels below the surface. Although natural radioactivity and conduction from the earth's core contribute small quantities of heat, the main drivers affecting soil temperature in the upper metres come from solar radiation and heat exchanges at the surface (AES, 1978). This heat process is dependent upon seasons, cloud cover, plant cover and physical soil properties such as soil type, compaction and moisture content (AES, 1978). As atmospheric processes are reflected in soil temperatures, tracking soil temperature can be a valuable variable in monitoring climate change.

The Meteorological Service of Canada has been studying soil temperatures for decades. There is considerable scientific interest in how soil temperatures differ according to forest type as well as its influence on insects, wildlife and vegetation. Research has shown that forests have a buffering ability, maintaining a climate that differs from that in a neighbouring open field. Snow can contribute to this effect by acting as a buffer in frost penetration (MacIver, 1998). Studies have shown that forest soils do not normally freeze in the winter due to the insulating effect of snow cover and the buffering capacity of forests. Forest biodiversity is linked to soil temperature as many forest systems are dependent on non-frozen soils (MacIver & Auld, pers comm). This raises questions in relation to climate change and its impacts on adequate snow depth and soil temperature, and how this will in turn impact biological species (MacIver & Urquizo, 2000).

Soil temperatures have an influence on ecosystem structure and function (MacIver, 1998; MacIver & Urquizo, 2000), The soil temperature profile of an area is important biologically in terms of what biodiversity can be supported and what can be grown in agricultural areas (AES, 1978). The metabolic activity of soil micro-organisms, seed fermentation and plant roots are directly influenced by soil temperature in terms of water movement and soil freezing (AES, 1978). Soil temperature information can also be important in the estimation of heat budgets, frost tendency, frost penetration in different ecosystems and soil moisture content (AES, 1978).

ASSOCIATED PROTOCOLS

Snow Depth: As forest biodiversity in temperate and boreal forest regions are highly dependent on non-frozen soils and the insulating effect of snow cover, monitoring temperature should always be paired with snow depth measurements in biodiversity monitoring programmes (MacIver & Auld, pers comm). Data collection methods for snow depth are written into this protocol.

Plant Phenology: Air temperature and soil temperature are two main influences on plant phenology and growth. Pairing soil temperature with plant phenology research can link soil temperatures with the flowering times of specific species and allow for prediction modelling.

Decay Rate: Processes such as decomposition are also dependent on soil temperature. In fact, rates of decomposition are practically zero in frozen soil (AES, 1978). Pairing soil temperature with decay rate information can allow for the profiling of decomposition in relation to temperature influences.

CHECKLIST OF MONITORING ACTIVITIES

- Identify research question
- Complete site establishment protocols and mark exact location;
- Prepare and Insert data logger and mark area
- Retrieve data logger and data and reinsert another prepared data logger
- Analyse data
- Send copy of data to the EMAN Coordinating Office for regional, provincial and national comparisons.

EQUIPMENT

- Data Logger (H20-0011-002 - HOBO Water Temp Pro)
- Protective Boot
- Software (BoxCar Pro 4)
- Meter stick (for snow depth measurements in winter)
- Fishing line
- Shovel or Trowel
- Ruler
- Wooden stake
- Data sheets and pens
- Site map
- Camera

RESEARCH QUESTION

Soil temperature monitoring involves placing temperature data loggers in the soil to record the temperature and the daily, monthly, seasonal and annual variation. The sampling design will vary depending on the research question or the objectives of the research programme. This basic EMAN protocol offers a few different options for recording soil temperature. Other sampling designs are also encouraged as long as

they include elements of this protocol so that the data collection is standardised to enable comparisons and integration at regional and national scales.

Soil temperature can be used to give background data to other monitoring programmes such as plant phenology, soil decay rate, species diversity, invertebrate studies, worm diversity etc. In associating soil temperature information with other protocols, soil temperature baseline information should be collected in the area that would most affect the main item under study. For example, in association with plant phenology or PlantWatch, the soil temperature at the plant root level (10cm) should be recorded. This can give an idea of the impact of soil temperature on growth and flowering times. In association with invertebrate diversity, soil temperature can be placed in the humus layer where many species forage or the deeper layer where the species over winter to see any patterns that emerge between soil temperature and diversity.

It is highly recommended that snow depth data be taken along with soil temperature. A simple snow depth protocol is provided (pg 8).

There are six steps in evaluating and designing research.

1. **Defining goals and objectives**:
   What does your organisation want to study and why. In terms of Soil Temperature, there are many different possibilities. We offer some suggestions and examples but it is by no means an exhaustive list of possibilities in terms of using Soil Temperature monitoring as part of a monitoring programme.
   - Simple goal - Your study involves a yes or no answer: Does the soil freeze? Is the soil temperature changing? Does soil temperature relate to plant phenology/soil decay rate/species diversity?
   - Comparative goal - Your study involves the comparison of two or more parameters: Does soil temperature in site A differ from soil temperature in site B (i.e. forests versus fields). Is soil temperature more variable in soil type A than in soil type B. What is the soil temperature relationship between topsoil and deeper soil?
   - Complex goal - Your study has various levels of investigation, asking a more complicated question: How is the soil temperature changing? What is the soil temperature regime in Site A? What is the soil temperature regime in multiple sites?

   For more involved questions such as – is the soil temperature changing and if so, why is it changing? – then soil temperature protocols will have to be paired with other monitoring protocols and will require more in-depth study.

2. **Sampling design**: Different sampling designs relate to different research questions.
   - Single Level Study: Recording soil temperature at a single depth in the soil.
   - Paired Level Study: Recording soil temperature at a single depth in the soil at two or more sites OR Recording soil temperature at two different depths.
   - Multiple Level Study: Recording soil temperature at multiple depths in the soil. Can be done at two or more sites.

In general, simple goal research can use single level studies while paired studies can be used for comparative goal research. Complex goal research relates to multiple level study but can also incorporate paired levels study and additional associated protocols.

3. **Methods for analysis**: This depends on the specific research questions being asked. Soil temperature can be graphed to find seasonal changes. Daily averages can be plotted against time on a line graph to show seasonal variations. If comparing sites, a graph from site A can be compared to site B graph to determine any differences in temperature changes or delays in soil warming/cooling. Soil temperature data can also be paired with air temperature for correlation. If collecting additional protocol data, graphs for soil temperature can be related to phenology events, snow depth and other criteria.
4. **Communicate the results**: Annual/bi-annual reports are a good way to record monitoring status and trends, and can be useful in determining whether current research goals and objectives are being met through the monitoring programme.
5. **Integrate monitoring into decision-making**: Once trends are detected and potential problems identified, decisions can be made on how to address the ecological issues. Initial monitoring can explore the status of a site, then research can be directed towards the question of "why". Why is this variable changing / degrading / disappearing. Environmental management tools can be incorporated into land use planning, area management and decision-making to mitigate problems and address environmental issues as they arise.

LOCATION

A site for monitoring soil temperature can be established in a forested area, near a river or lake or near a wetland. This protocol can also be done in association with forest biodiversity monitoring plots.

Sites need to be easily accessible and free of hazards. In all cases once a site it chosen, fill in a *site description datasheet* for the location. Site characteristics need to be recorded and the soil temperature station should be plotted on a site map. Photographs of the site may also be useful in describing the sample area.

Placement of Data Logger

Data loggers should be buried in an area of the site that:

- Has soil that has been left undisturbed for four or more years.
- Is representative of the site.
- Is a good distance from any source of heat such as heated buildings or man-made objects.
- Is close to or under trees as this is usually an indication of good soil
- Is in an area which is easy to find and easy to access for sampling purposes.
- Is on a flat and level surface, preferably covered with vegetation (AES, 1978).

Data loggers should NOT be buried in an area of the site that:

- Is in a forest gap. There is usually a reason why these are gaps in the forest such as poor soil quality, which may not be representative of the site under study.
- Is inside a research plot, as placement of data loggers requires the disturbance of soil.
- Is next to rocks as they can affect temperature, unless the area is entirely rocky, in which case rocky soil is representative of the site.
- Is in depressions or on slopes where unusual moisture conditions could exist (AES, 1978).

Associated Protocols

If soil temperature monitoring is being paired with other protocols such as plant phenology or decay rate, soil temperature readings should be taken near the same site in order to represent the area understudy. However, as the soil protocol requires disturbance of the soil, do not locate the data logger directly in the area under study.

Paired Studies

When comparing two or more sites and/or soil types, try to reduce outside variables as much as possible. Place data loggers in similar areas in all sites (i.e. Northeast side of site, flat area, in vegetation etc). Ensure that all data logger burial sites are visibly marked and easily accessible.

Forest Biodiversity Plots

If you are associating soil temperature readings with a **forest biodiversity plot**, choose a data logger station on the southeast corner, outside the plot. Do not set up a station inside the biodiversity plot as this will increase traffic in the area under study. Mark the location on a plot map for observation in subsequent years.

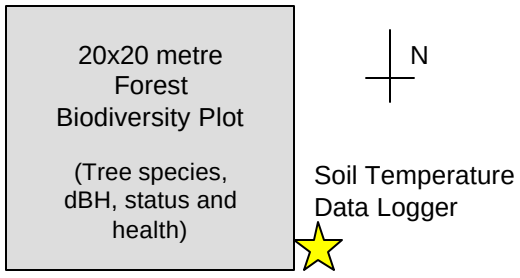

Figure 1. 20x20m Plot with data logger placement.

Habitat Type and Depth of Data logger

In order to study biodiversity and impacts of climate change, the most useful information on soil temperature comes from the layer used by biological species.

As a general recommendation, in studying plant biodiversity, soil temperature should be recorded at the root layer as this is the most important layer for prediction purposes. At a single depth, 10cm into the mineral soil (after the organic or humus layer has been cleared) is the depth most recommended (MacIver & Auld, pers comm). For multiple

layer studies, loggers can be set up in the mineral soil at 10cm, 20cm and 50cm, as a 50cm depth will be relatively stable in terms of temperature variation.

Generally, the organic layer or 5cm into the mineral soil is too variable and the data too spiky to follow changes over time. However, if the subject under study is a specific invertebrate species, the habitat of insects, mould or disease, recording soil temperature in the organic layer would be recommended.

Open areas are considerably more variable in terms of soil temperature than closed forests and the soils in open areas will generally freeze. Therefore in forested sites, data loggers should be placed in the forested areas (unless a paired study is being conducted) and should be placed 10cm into the mineral soil, *not including the organic layer* (see figure 2*)*.

Ecozone(s) and site types should be taken into consideration when determining logger depth placement. The following are areas that will require different depths for data loggers:

- British Columbia Coastal Forests: The organic layer in West Coast Forests can be very deep and does not normally freeze due to mild climate. This area has different thermal profiles than boreal forests. Again, it will be important to place data loggers in the plant root zone, which may be in the humus layer. It is recommended that an initial investigation into the ground vegetation root layer be done in order to determine the depth of burial. In general, the root zone is located10-20cm into the organic layer.

- Wetlands: Wetland areas are also made up of deep layers of organic soils. Bogs and black spruce swamps tend to have shallow rooted species and data loggers can generally be buried 10cm into the ground, including the organic layer. Depending on the wetland habitat type, initial investigation of the root zone should be done and the data loggers placed accordingly (generally 10-20cm below the surface in the organic layer)

- Grasslands: Soil temperatures in prairie areas will be more variable due to wind and open field conditions. Soils in open areas tend to freeze over winter in northern areas. Data loggers can still be placed in the mineral soil at a depth of 10cm, but the logger will need to be able to record temperatures below $-5^{o}C$.

SOIL TEMPERATURE MONITORING METHODS

Timing

1. Placement of the logger should be done in the warmer season, preferably summer as the temperature changes occurring in spring and autumn are important for soil study and phenology.

2. Collection of the loggers and replacement will depend on the monitoring programme. Is the data needed seasonally or annually? If data is needed seasonally, four data loggers can be placed at the site and one collected per season (instead of removal and replacement each time), to ensure a minimum amount of soil disturbance and a continual sample.

Preparation

1. The data logger recommended for this protocol is outlined below:

HOBO Water Temp Pro	
Cost	~ $175.00 each
*Other Required Items***	IR Base-station GST-IR1 ~$100.00
*Software***	BoxCar Pro 4.0 ~$160.00
Protection Boot	Recommended boot ~$25.00
Replacement	Battery replacement (send back to manufacturer) ~$90.00
Possible Retailers	Hoskin Scientific - www.hoskin.ca

** Note that only one software/basestation is needed per organisation despite the number of data loggers buried. The logger is battery replaceable.

2. Obtain data logger and the appropriate protective cover, Basestation and Software.
3. Read *BoxCar Pro User's Guide*, the *User's Guide for Launch Readout Software for the HOBO Water Temp Pro* and the *Data Logger User's Manual* before beginning.
4. Install BoxCar Pro Software as per the BoxCar Pro User's Guide instructions. This software allows users to launch the logger, record data, display plots, adjust and customise views, display information, export plot data and analyse data with filters.
5. Install IR Communications Cable (Basestation) to available serial port – please note that the IR Basestation requires a direct connection to a standard 9-pin serial port.
6. Follow instructions for logger operations and set up.
7. Align logger with Basestation as per instructions and launch logger to set parameters:
   - *Set Logging Interval*: this will determine how often the logger will take sample measurements. It is recommended that the logger record data at ***one hour*** intervals in order to provide a daily profile of temperature fluctuation, though this may not give the absolute maximum and minimum daily temperatures.
   - *Start Option*: this will determine when the logger starts recording data. It is recommended that the start be postponed until the day after the logger is placed in the field.
   - *Data Recording Option*: this will determine what the logger will do when its memory is full. If you select continue recording, this will overwrite oldest data with newer data, until data is downloaded. It is recommended that you select stop recording when logger is full unless you plan on offloading data continuously throughout the year, therefore old data will have already been recorded elsewhere when memory is full and it can be overwritten.
   - *Stealth Mode*: this will determine whether or not the LED operation indicator will blink to show logger is operational. It is up to the individual user if you would like stealth mode or not, however if on stealth mode it will be difficult to tell in the field

if the logger is operational without downloading information. The LED light also provides a visual indication of operational state (i.e. full memory, recording etc.).

Please note that the battery life of the logger is estimated at 6 years in environmental conditions of 25^{o}C. For colder climates, the conservative estimate is a two-year battery life.

Installation and Marking

Installation should be done with the least amount of disturbance to soils as possible:

1. Attach a 3m piece of nylon fishing line to the case of the temperature logger.
2. Check that the light on the temperature logger is blinking, to confirm that the logger is operational (unless stealth mode is in effect – in which case you will not be able to ensure that the logger is operational).
3. Using a shovel or trowel, dig a small trench – see **LOCATION** section for site placement instructions.
4. Measure down 10cm from mineral soil layer (For multiple layer studies, follow the same procedures for 20cm depths and 50 cm depths. Do not place data loggers directly under each other, move slightly right or left of upper loggers).
5. Secure the fishing line on data logger(s) to a wooden stake
6. Place a wooden stake into the trench and push the attached data logger thermometer(s) sideways into the trench so as not to disturb the above soil (see Figure 2).
7. Backfill the trench with the stake sticking out and map the area for future reference.
8. Fill out site information on Soil Temperature Data Sheet.

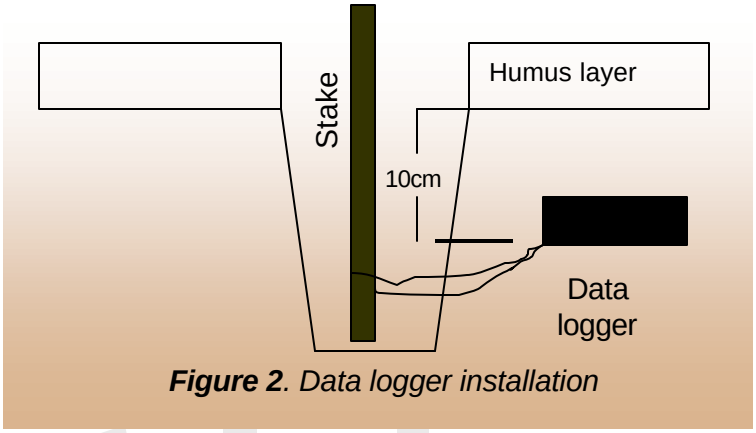

***Figure 2**. Data logger installation*

Snow Depth Measurements

1. Snow depth measurements should be taken along with soil temperature.
2. The frequency of snow depth measurements should be decided upon depending on the accessibility of the site and the availability of a volunteer or field researcher to record snow depth. It is recommended that snow depth be taken at least twice monthly and more whenever possible.
3. To record snow depth, go to monitoring site and locate burial site using the map and the stake.
4. Place a meter stick into the snow down to the soil. If snow levels are higher than one meter, mark meter height and measure excess.
5. Record snow depth in cm on the soil temperature data sheet.

Data Collection

Prior to returning to field, ensure that you have a replacement HOBO Water Temp Pro data logger if it has been approximately two years and a battery replacement is needed. The battery is factory replaceable and therefore the entire logger must be sent in, so a second logger is needed for field studies. Follow instructions for data logger set up and

launch and installation. Otherwise, data can be downloaded and the original logger replaced.

- At the predetermined removal time (4 months to two years after placement) return to the monitoring site.
- Briefly review the site and station establishment data sheets and confirm that there has been no change.
- Locate the wooden stake in the field.
- Check and renew the point marker (wooden stake) if it has become difficult to identify.
- Using a trowel carefully excavate a trench around the wooden stake. Once attached fishing line has been located, pull and remove data logger (try not to disturb the soil above the data logger through compaction.
- Check that the LED light on the temperature logger is blinking, to confirm that the logger is operational (unless in stealth mode).

Reading out Data:

- To read data there are two options. You can either stop logging before offloading data, which will erase all previous data from logger memory once offloaded. The second option is to offload while logging so that all previous data will not erase, and the logger can be replaced in its ongoing state.
- Depending on reading out option, download the data collected by the temperature logger.
- Record the date on the Soil Temperature data sheet.
- Replace HOBO data logger, or install new HOBO data logger and send the old logger in for battery replacement.
- Using a ruler, reconfirm the 10cm depth.
- Place the temperature logger in the bottom of the hole and tie the loose end of the fishing line on the wooden stake.
- Replace the wooden stake and backfill trench. Reconfirm site location on data sheet.

DATA ANALYSIS

It is recommended that organisation of data be done through the use of BoxCar pro. Data can also be exported to a spreadsheet or graphing programme for further analysis.

Once the data has been exported, check the output for missing data or unusual sequences of values. Using the data, calculate daily average temperatures over the specified time periods (seasonally, annually etc). Calculate mean temperature to the nearest tenth of a degree (e.g. 8.9) using AES standard round-off procedures:

- If the fractional part to be disposed is five or more, increase the preceding digit by one (i.e. 2.55 = 2.6 and -2.55 = -2.6).
- If the fraction part to be disposed is less than five, do not change the preceding digit (i.e. 6.34 = 6.3 and -6.34 = -6.3).

Using daily averages, conduct data analysis as per research question, through the use of graphing. If multiple depths are used calculate the sum and mean of the temperature at each depth and graph.

Pair air temperature of the area with soil temperature and/or with additional protocol data to identify relationships. For local information, compare yearly profiles with weather events and snowfall.

Use the snow depth measurements and relate this to soil temperature to see if depth has a buffering effect. If associating soil temperature with other protocols (such as plant phenology), compare associated protocol data with and soil temperature changes.

National Data Analysis

EMAN CO encourages soil monitoring at sites throughout Canada along transects and/or across ecological gradients for comparable changes. Once soil temperature information is collected and sent in to EMAN CO, we can work towards providing a regional, provincial and/or national picture of soil temperature profiling in order to establish a baseline and track changes to allow for long-term prediction.

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EMAN Ecosystem Monitoring Partnership

SOIL TEMPERATURE DATA SHEET

SITE INFORMATION

SITE NAME:	NEAREST NAMED PLACE:	
OBSERVATION AREA DESCRIPTION (FOREST/WETLAND):		
FOREST TYPE:	SOIL TYPE:	
LATITUDE/LONGITUDE:	COUNTY/TOWNSHIP:	PROVINCE:
OBSERVER NAME(S):	OBSERVER ADDRESS: TELEPHONE: EMAIL:	

Station Name (1, 2, 3 etc)	Date of Placement / Replacement (dd/mm/yr)	Date of Extraction and Readout (dd/mm/yr)

SEND DIGITAL DATA ON SOIL TEMPERATURES TO EMAN CO
eman@ec.gc.ca

Snow Depth Monthly Record

Date (dd/mm/yr)	Snow Depth (cm)