Carbon in ecosystems of Central Siberia: the effect of forest invasion to tundra

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CryoCARB

Leibniz Universität Hannover

How forest vegetation freezes the soil

ESF JRP: Long-term Carbon Storage in Cryoturbated Arctic Soils

Cryocarb

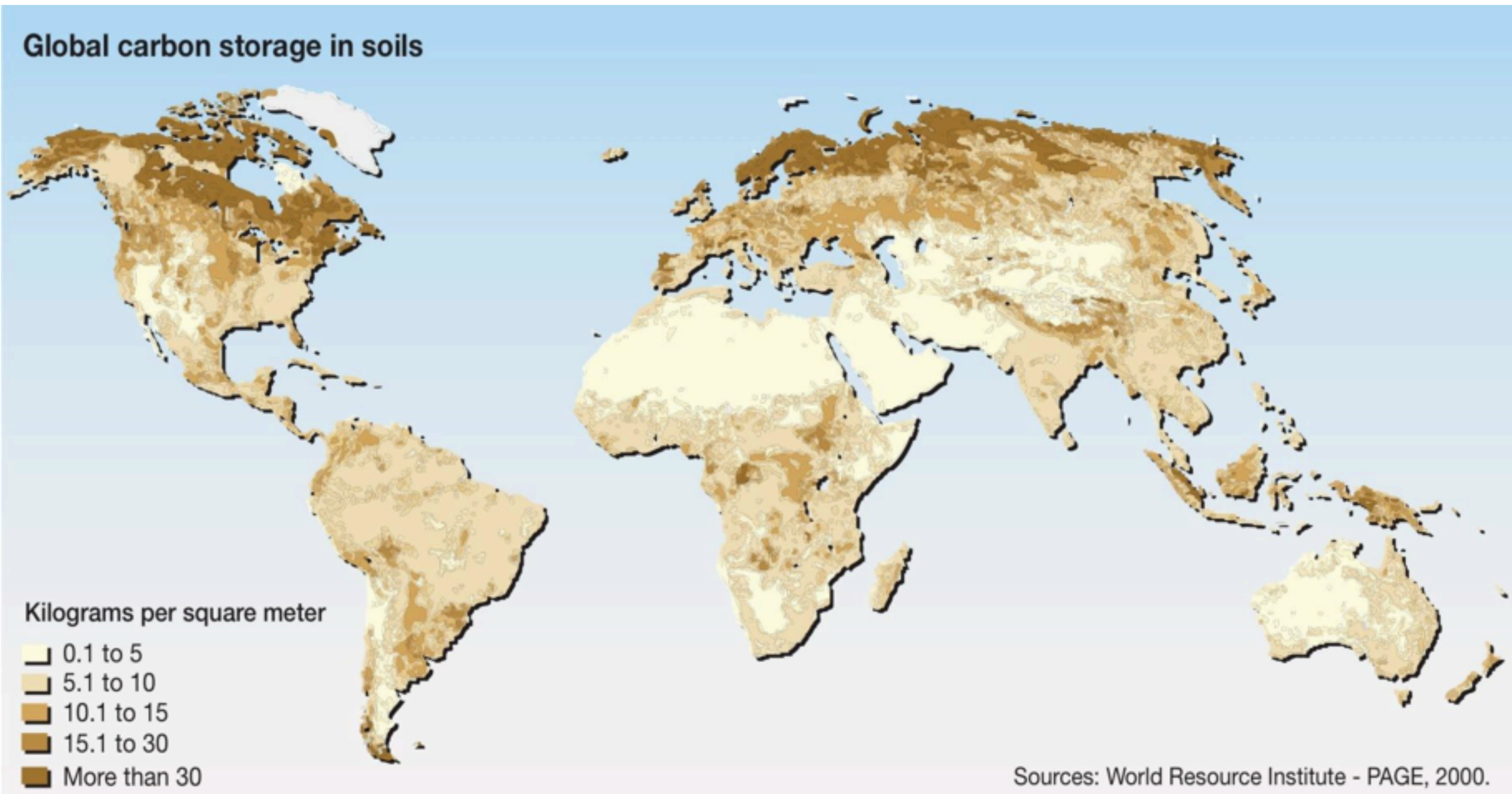
- The **overarching goal** of CryoCARB is to advance organic carbon estimates for cryoturbated soils, focusing on the Eurasian Arctic and to understand the vulnerability of these carbon stocks in a future climate.
- The constraints to our understanding of carbon dynamics in cryogenic soils are currently manifold:

First, due to cryoturbation, organic matter is unevenly distributed within the soil, making SOC estimation very difficult. There is evidence that the North American arctic carbon stock is bigger than previously thought, also because of underestimation of carbon stored in distorted, broken and warped horizons **[4]**.

Second, most studies dealing with SOC in arctic soils fail to account for carbon stored in the upper permafrost, although the latter is directly under threat in a rapidly warming Arctic **[1]**. Thawing of the upper permafrost will also mobilize old, geogenic C [8], which is rarely addressed.

Third, the mechanisms of carbon stabilization are largely unknown thus hampering the prediction of climate-CO_2 feedbacks **[3,5]**. Knowledge of the chemical composition of organic matter and the processes on how carbon is stabilized is necessary to predict the magnitude and the time-scale at which SOC will get remobilized from thawing permafrost under climate change **[9]**.

Cryosols are reservoir of 747 Gt C in the upper 3 m, excluding peatlands and carbon in deep loess sediment



Problem

Accelerated decomposition and release of ancient soil carbon in extensive Tundra biome (12 million km^2) upon global warming may cause significant increase of net C fluxes to atmosphere in Northern Hemisphere

McGuire et al. (2010)
Shaver et al. (2006) *J. of Ecology*
Corradi et al. (2005) Global Change Biol.
Etc.

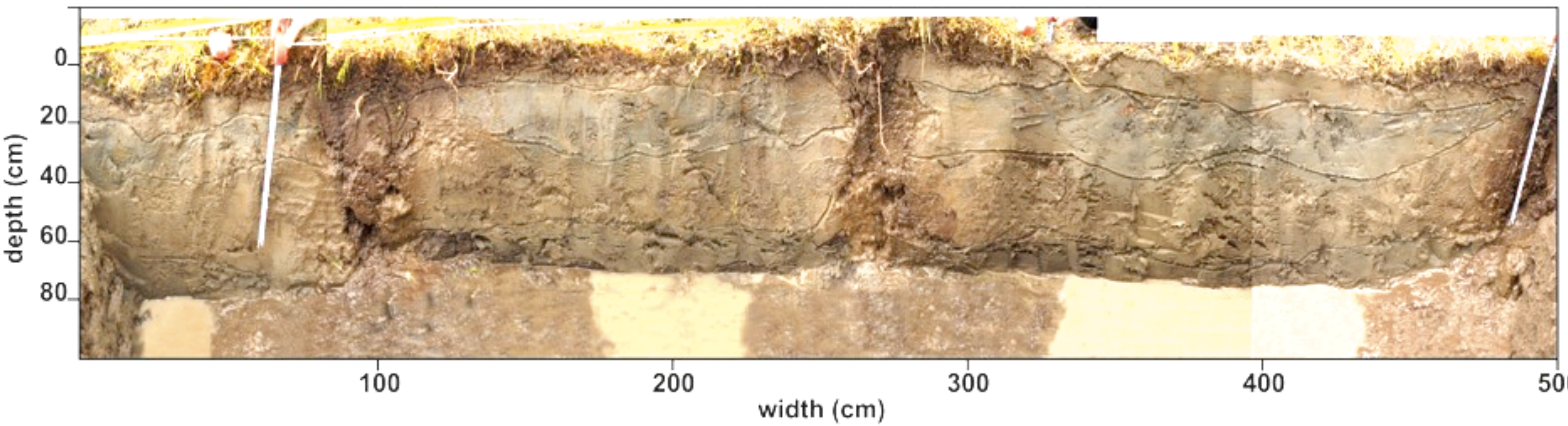
Climatic response of permafrost soils will vary significantly with (i) **location (e.g. tundra subzone), (ii) SOM quality, (iii) involved stabilization mechanisms and (iv) invasion of woody vegetation.**

Key goal of “Cryocarb” Project is to obtain the explicit information on factors from i to iii, which are specifically important with regard to cryoturbation processes

Gundelwein et al. (2007) *Eur. J. SoilSci.*

Associated project (RFBR #10-04-01003) “Stabilization of organic matter in cryoturbated soils of Siberia” aimed to estimate the role of forest invasion to tundra in carbon budget

Examples of Cryoturbation processes and OC distribution within the soil



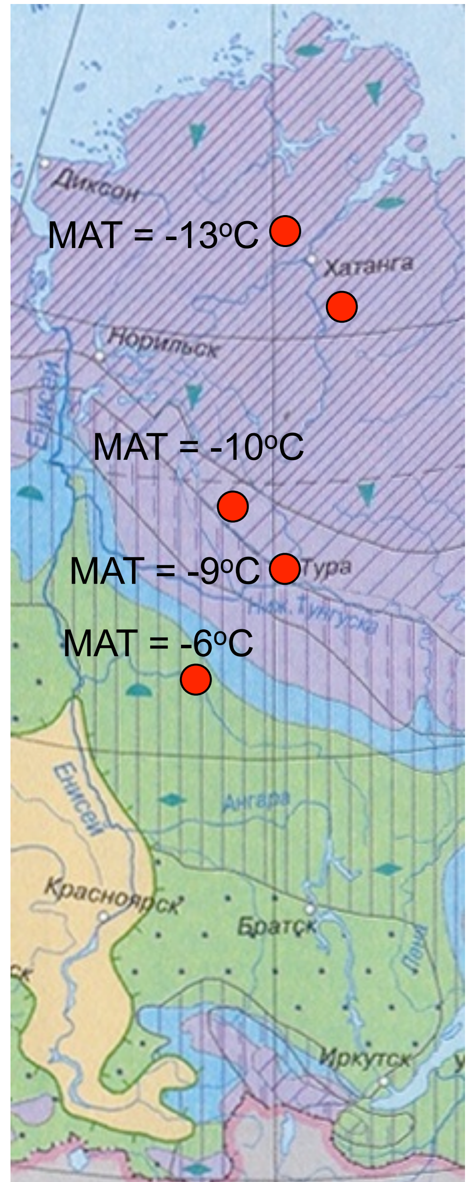
Research objectives: go into forest-tundra ecotone and…

- Determine OC storage in vegetation and soil
- Assess ecosystem-scale variability in OC stocks between tundra, sparse and closed forests
- Study transformation of soil organic matter by isotopic and biomarker fingerprints

Study sites

- Taymyr (Ary-Mas)
  - **3 transects**
- Anabar (Kyndyn)
  - **1 transect**
- Putorana (Tembenchi)
  - **2 transects**
- Tura
  - **3 transects**
- Baykit
  - **survey is planned in near future**

No tundra sites



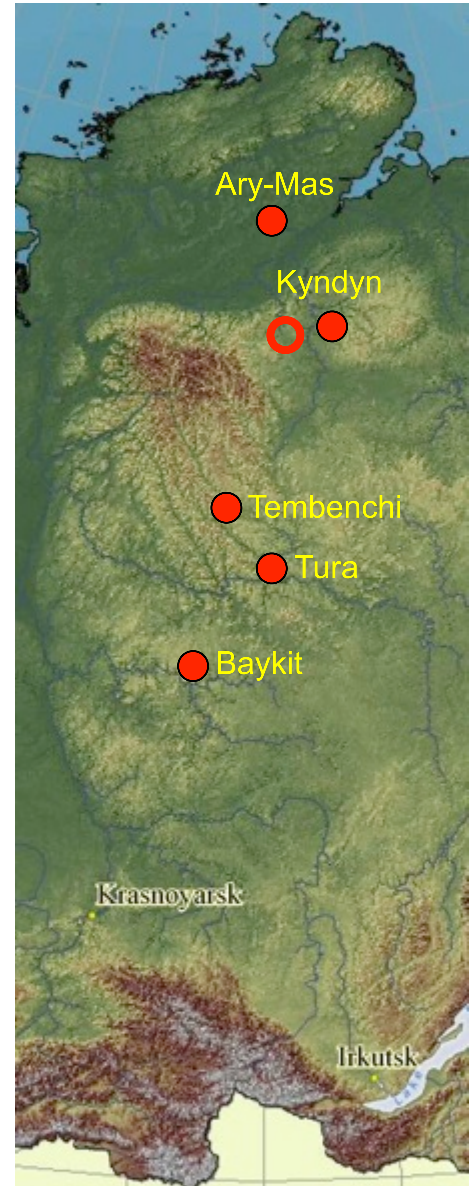


Table 1. Characteristics of altitudinal transects (upland landforms) within Central Siberia.

Transect, number of plots	Coordinates	Altitude, m a.s.l.	MAAT, ^{o}C	Vegetation	Soil properties	
					Patterned ground, %	stone content, %
Ary-Mas n=11	72°30' N 102°30 E	20-90	-13.8	southern tundra-larch forests	0-35	0-10
Kyndyn n=4	70°52' N 102°56'E	70-370	-13.1	mountain tundra-larch forests	0-40	5-25
Tembenchi n=25	65°25' N 97°35' E	200-900	-10.8	mountain tundra-larch forests	0-50	5-90

Structure of presentation

- *Some words about forest research in high latitudes of Northern Eurasia and Northern America*
- *Tree-line advances and retreats in past*
- *Present forests: tree generations and TRW (Ary-Mas case study)*
- *Vegetation biomass, soil organic carbon, soil temperatures and permafrost on altitudinal transects of Taimyr, Anabar and Putorana Plateaus*

Current knowledge about forest-tundra terrains

- *Taimyr forest research history: Middendorf 1867, Tolmachev 1920s, Tyulina 1930s, Lovelius 1970s-80s, Naurzbaev 1990s-2000s*

- *Numerous dendroclimatic studies in Circum-arctic Eurasia (publications of McDonald, Briffa, Vaganov, Naurzbaev etc.)*

- *Forest invasion to the tundra:*

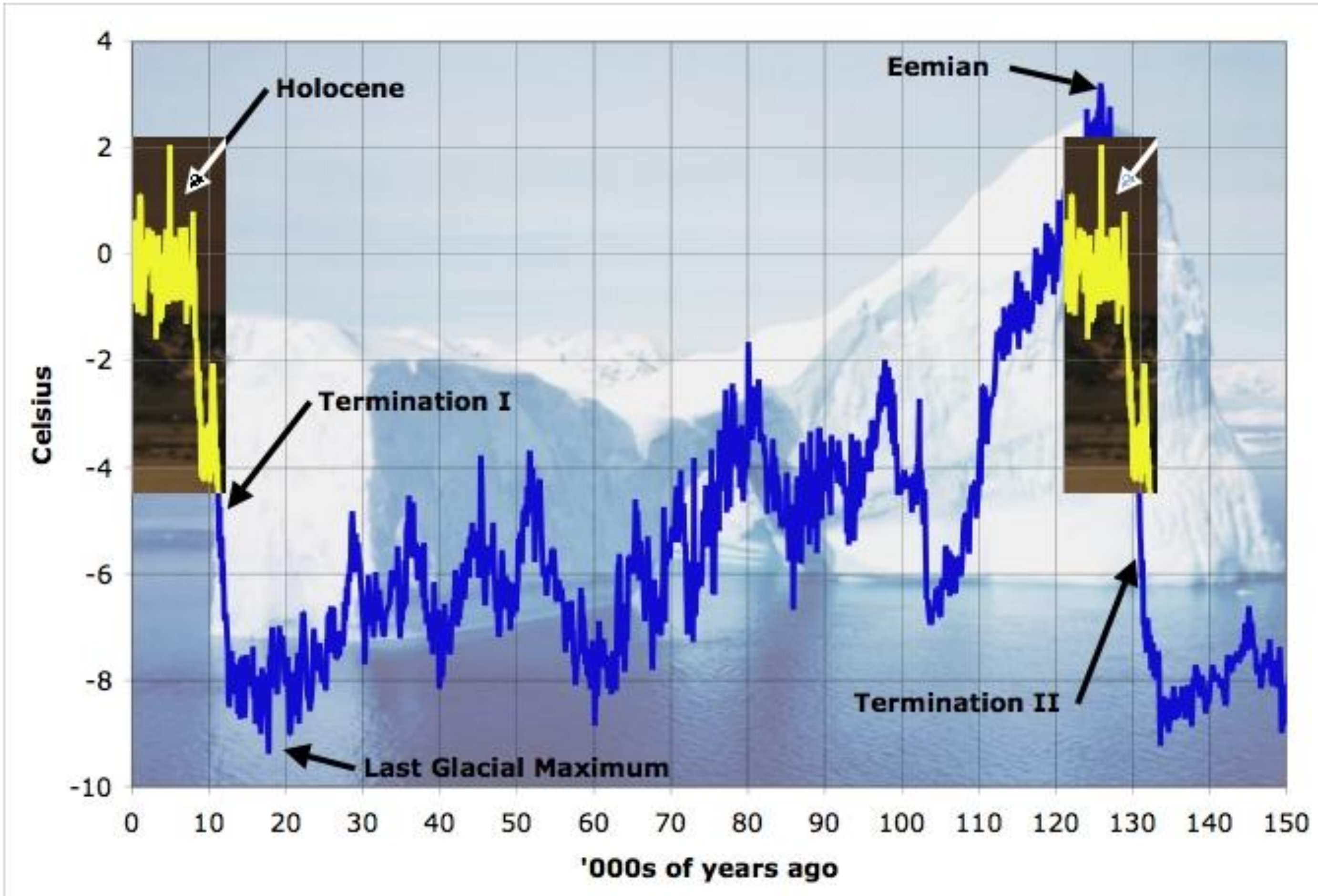
- Polar Ural (Shiyatov et al. numerous publications)
- Taymyr Peninsula (e.g. Kharuk et al., 2004, Ranson et al., 2004)
- Alaska (e.g. Suarez et al., 1999)

- *Vegetation change (e.g. Sturm et al., 2001, Tchebakova et al., 2009 etc.)*

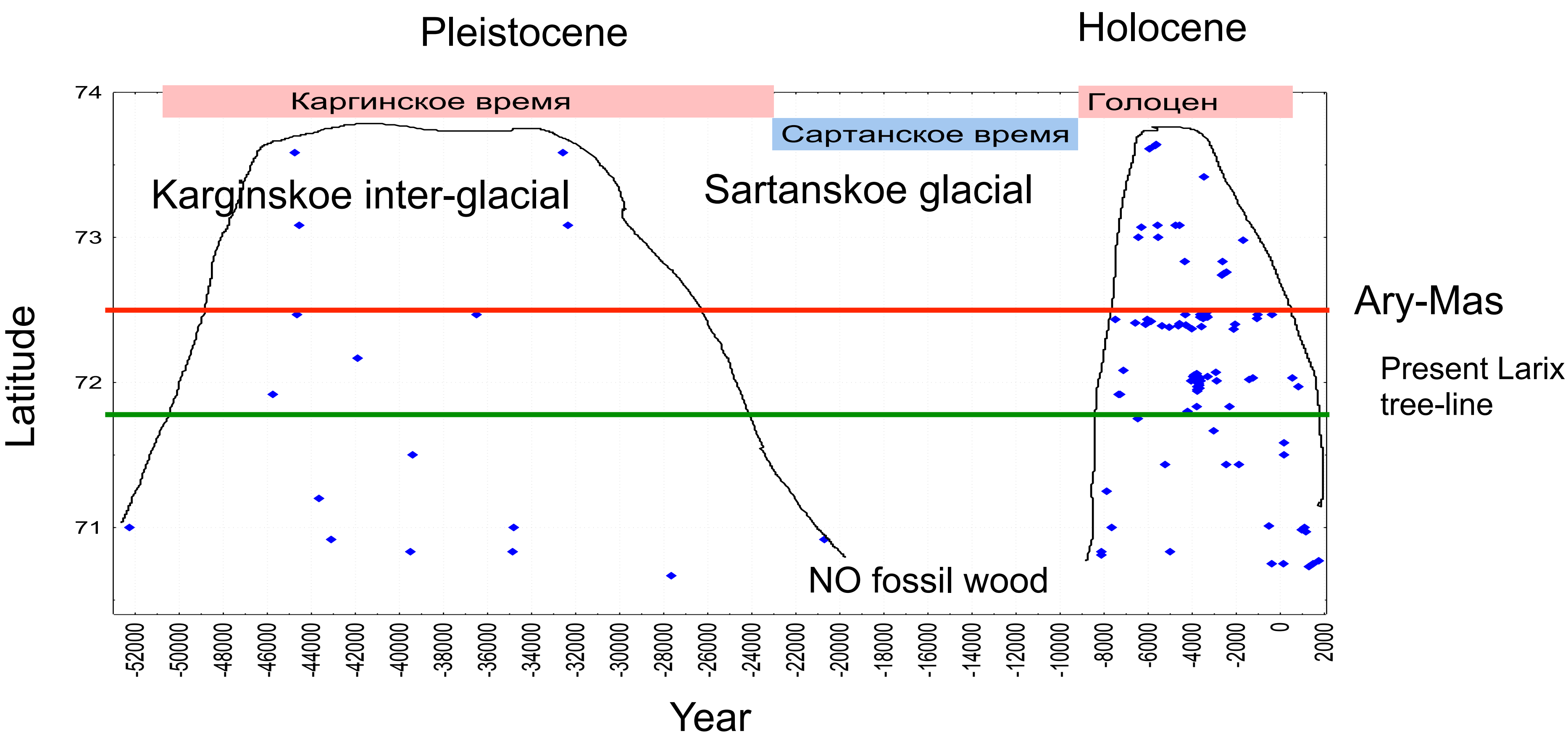
- *Effects of woody species invasion to tundra on soil C stock are controversial:*

- Positive (e.g. Steltzer 2004)
- Negative (e.g. Wilmking et al. 2006)

Global temperatures for last 150,000 years



Taimyr tree-line advances and retreats: 50,000 years



- Dating based on Larix wood macrofossils distribution in Taimyr Peninsula during the last 50,000 years (Naurzbaev, Vaganov, 2000; Briffa et al., 2000, Naurzbaev et al., 2002, 2003 http://www.cru.uea.ac.uk/cru/people/briffa/qsr1999).

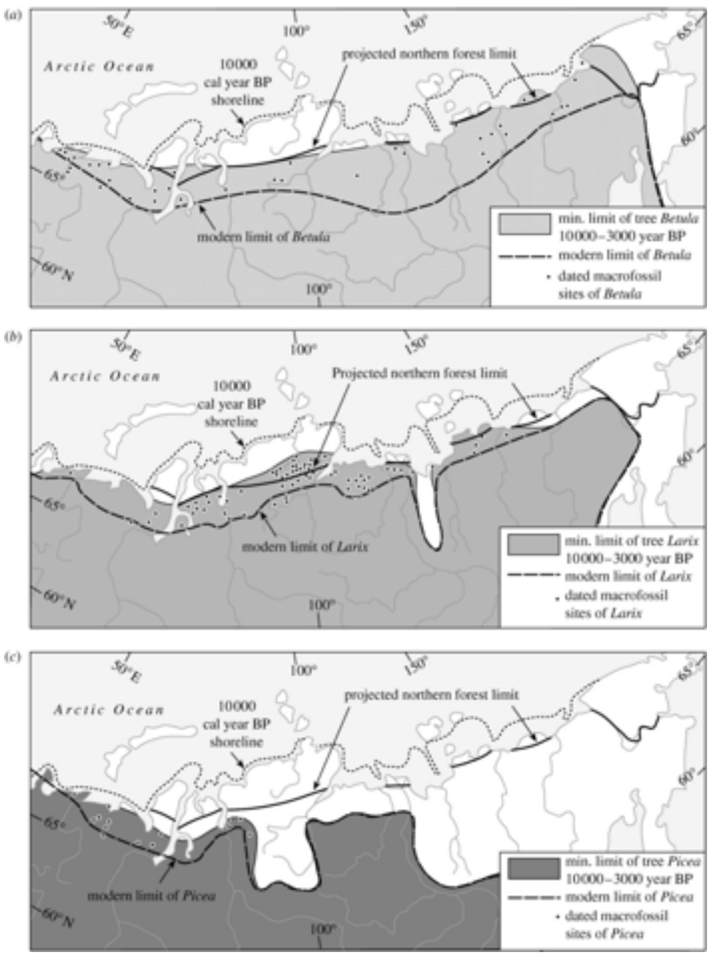
Fossil wood

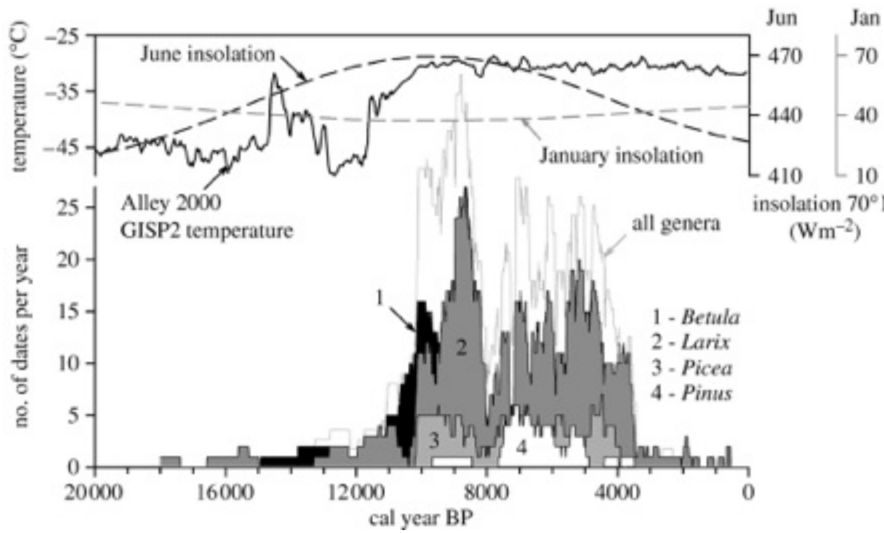
Fossil wood in eroded river bank of Khatanga River – large peat deposit

Fossil wood on the lake bank in 3 km from Novaya River (ca 60 m a.s.l.)

Tree-line advances and retreats: Holocene optimum (10,000-3,500 years BP)

MacDonald G et al. Phil. Trans. R. Soc. B 2008; 363:2283-2299

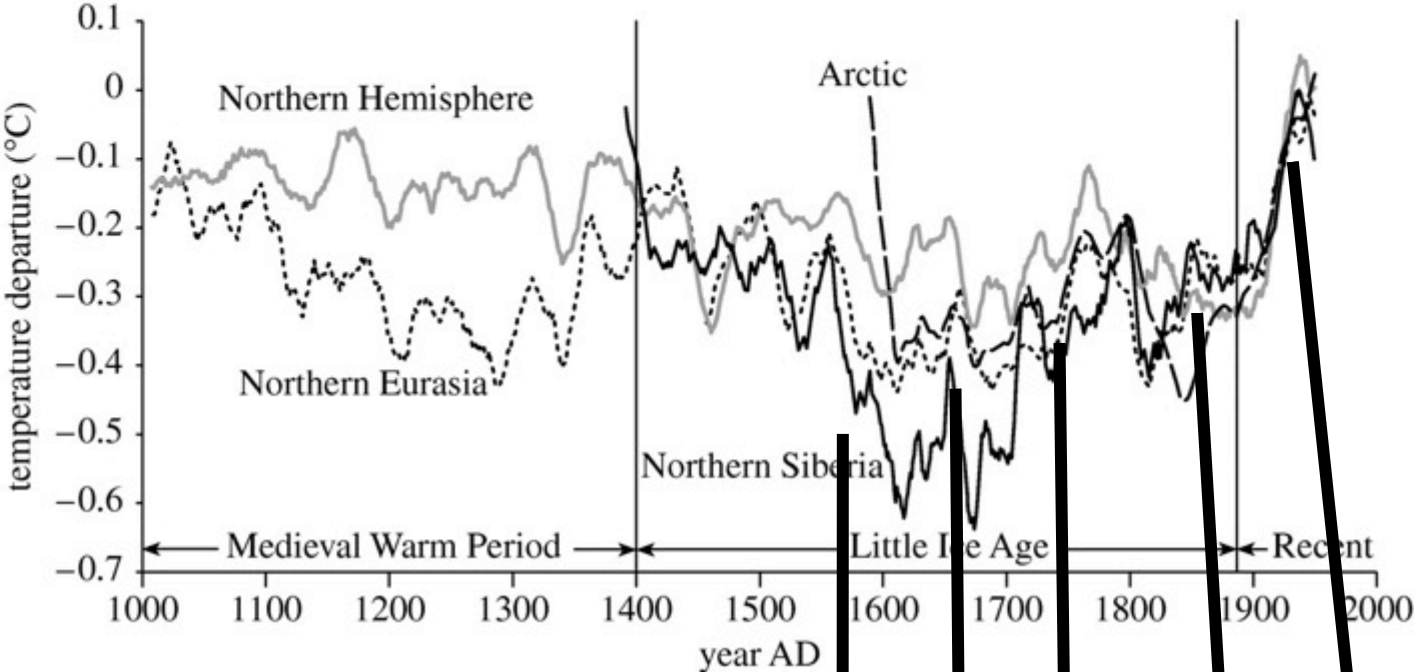


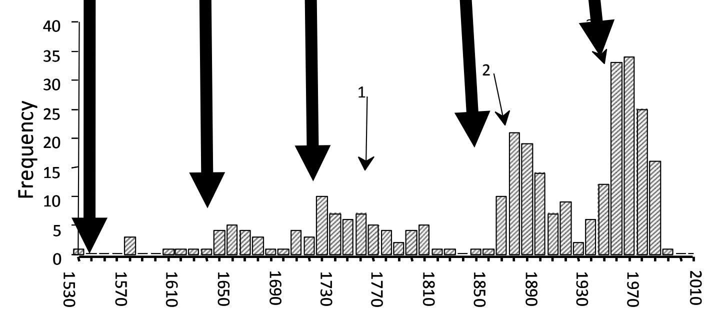


- **forest-tundra ecotone shifted ca. 300 km north 10,000 years BP and retreated ca. 3,500 years BP.**
- **NB: SOC older 3,500 years has been formed in forested terrain.**

Northern Hemisphere (Mann et al. 1999), Arctic (Overpeck et al. 1997) and northern Eurasian (Briffa & Osborn 1999; Briffa 2000) summer surface-temperature trends over the past 1000 years (adapted from Overpeck et al. 1997; Briffa & Osborn 1999; Mann et al. ...

Cit.: ***MacDonald G et al. Phil. Trans. R. Soc. B 2008; 363:2283-2299***





Naurzbaev 2005

- Tree establishment generally coincides with temperature peaks
- Large frequency of trees established in 20th century

Approaches

- Stand

- Measurements of DBH and H (tree census):
- $S = 200\text{-}10{,}000\ m^2$
- >150 trees/plot
- All seedlings

- Tree cores (n=15-25) and discs (n=5) for TRW measurements

- 5-10 seedlings for age and biomass measurements

- **Biomass** through allometric equation (Bondarev et al. 1970)

C stock estimate: sampling and measurements of ground vegetation and soil

- **Shrubs (*Salix* spp., *B. nana*, *D. fruticosa*)**
- Cross transect (10×1 m)
- Stem counting and measurement of total weight of samples (n=3-5)
- **Ground vegetation: 5-7 subplots (25×20 cm)**
- Dwarf shrubs (wet weight, subsamples to dry)
- Grasses (wet weight, subsamples to dry)
- Moss/lichen layer (wet weight, subsamples to dry)
- **Topsoil: 5-7 subplots**
- O horizon: (20×20 cm, wet weight, subsamples to dry)
- Upper 0-5 cm: 5-7 subplots (1-3 cylinders)
- **Subsoil: 1 soil pit across mound and trough**
- Sampling at 0-5, 5-10, 10-20,… and upper 10 cm of permafrost (1-3 cylinders)
- Soil temperature (every 5 cm)

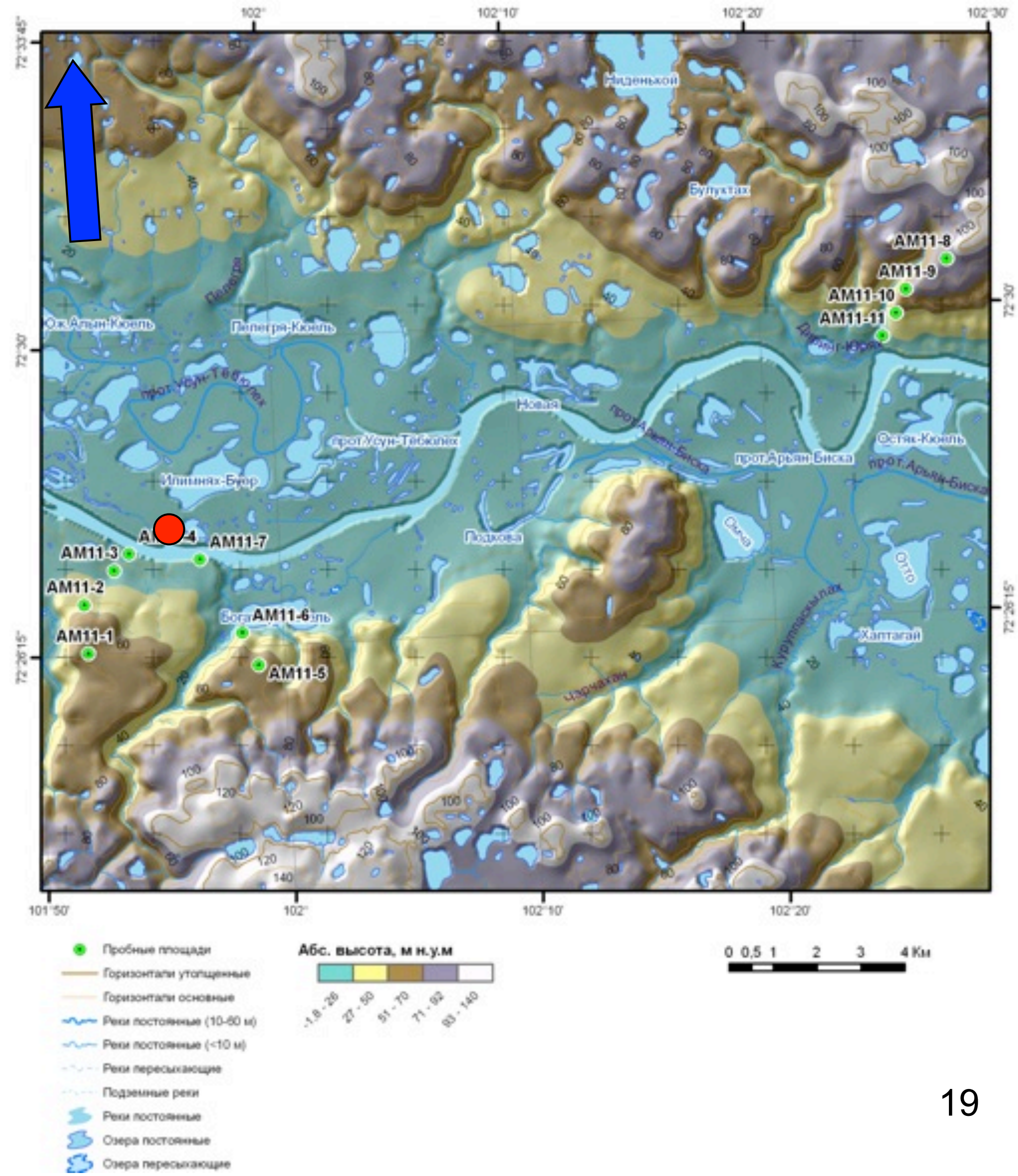
Taimyr Peninsula: Ary-Mas site

- <u>3 altitudinal transects:</u>
- 2 north-facing slopes
- 1 south-facing slope

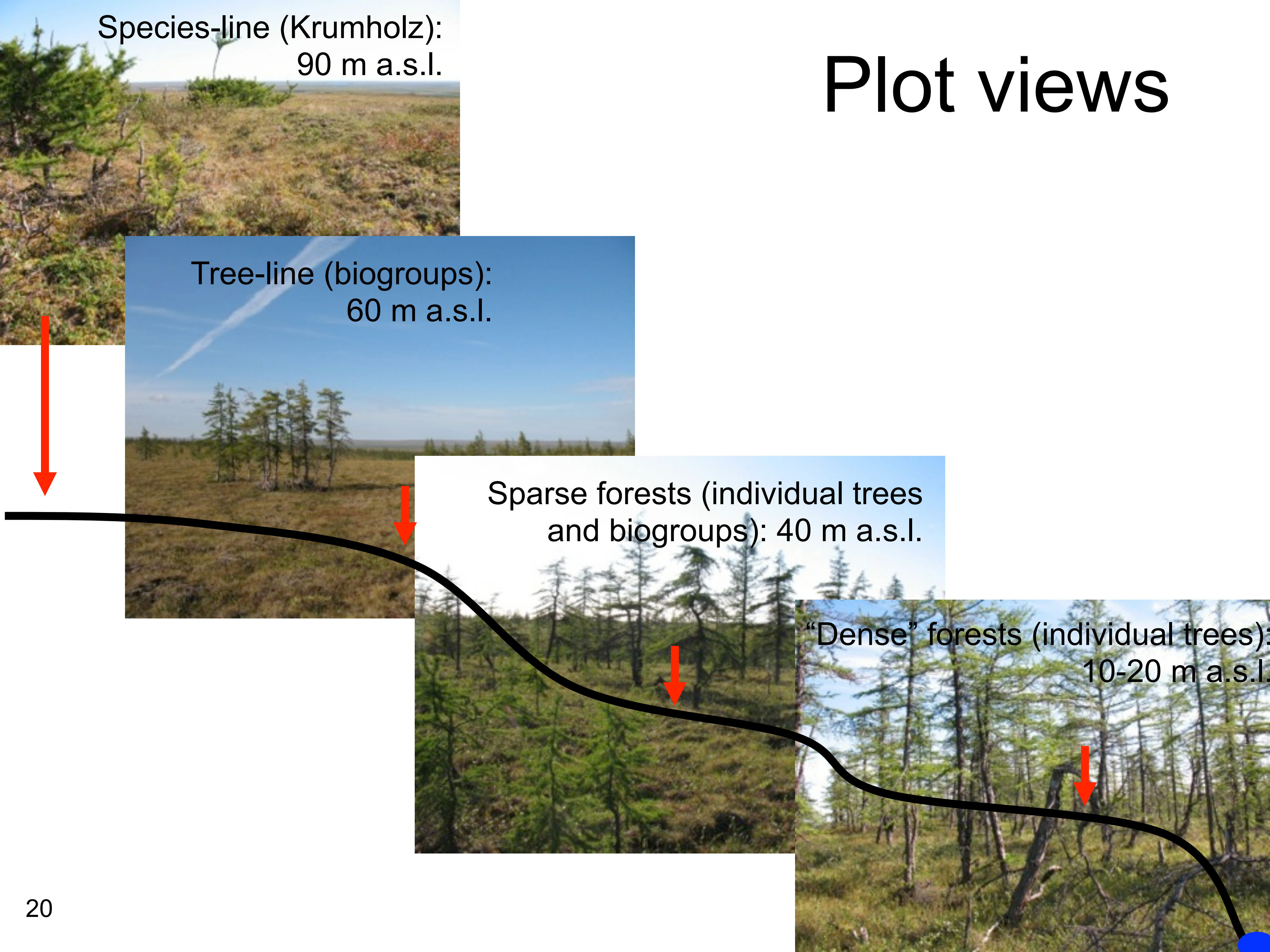
- <u>N-facing:</u>
- tree-line - 60 m a.s.l.
- sparse forests - 40 m a.s.l.
- “dense” forests – 10-20 m a.s.l.

- <u>S-facing slope</u>
- species-line (krumholz) - 90 m a.s.l.
- sparse forests – 60-20 m a.s.l.

Total number of plots: 11



Plot views


Species-line (Krumholz):
90 m a.s.l.
Tree-line (biogroups):
60 m a.s.l.
Sparse forests (individual trees
and biogroups): 40 m a.s.l.
“Dense” forests (individual trees):
10-20 m a.s.l.

	Tree-line	Sparse forest	Sparse forest	Closed forest
	Transect 1			
Altitude, m a.s.l.	60	40	20	10
DBH, cm	5,69	8,73	10,77	9,55
H, m	5,72	7,47	8,51	7,90
Tree density, ha^{-1}	155	430*	400*	1860
"closinest"	0,04	0,11	0,14	0,35
Basal area, m^2/ha	0,77	2,53	3,57	8,71
Wood stock, m^3/ha	2,65	10,45	16,27	37,56
Wood stock, kg/m^2	0,14	0,55	0,85	1,97
	Transect 2			
Altitude, m a.s.l.	60	40		20
DBH, cm	6,82	5,32		7,09
H, m	6,41	5,49		6,56
Tree density, ha^{-1}	195	720		1950
"closinest"	0,03	0,08		0,33
Basal area, m^2/ha	0,70	1,57		7,54
Wood stock, m^3/ha	2,59	5,23		28,43
Wood stock, kg/m^2	0,14	0,27		1,49
	Transect 3			
Altitude, m a.s.l.	60	40	20	
DBH, cm	5,60	5,94	4,38	
H, m	5,67	5,88	4,86	
Tree density, ha^{-1}	125	195	415	
"closinest"	0,01	0,02	0,03	
Basal area, m^2/ha	0,30	0,53	0,61	
Wood stock, m^3/ha	1,03	1,85	1,89	
Wood stock, kg/m^2	0,05	0,10	0,10	

Northern aspect

Southern aspect

* Logged in the past

Tree growth

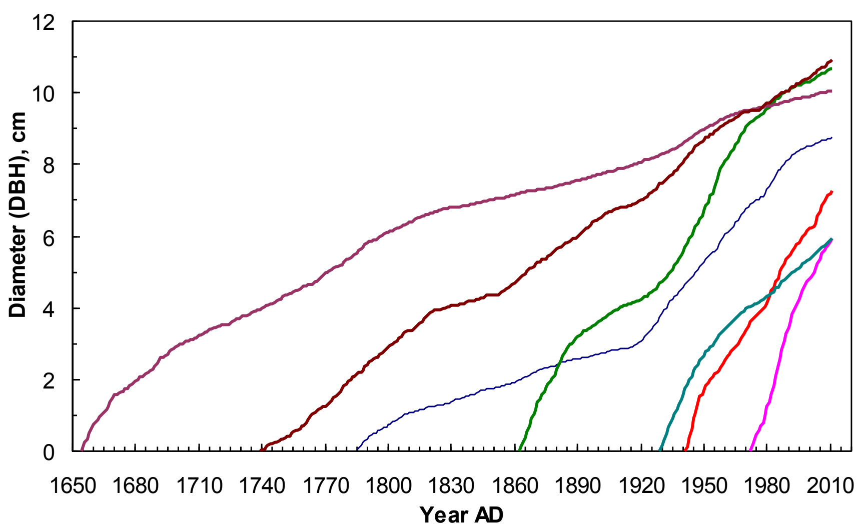
Uneven age structure: forests consist of 4-7 generations of larch trees (the oldest dated by1530)
No fire effect: no one tree with fire scare

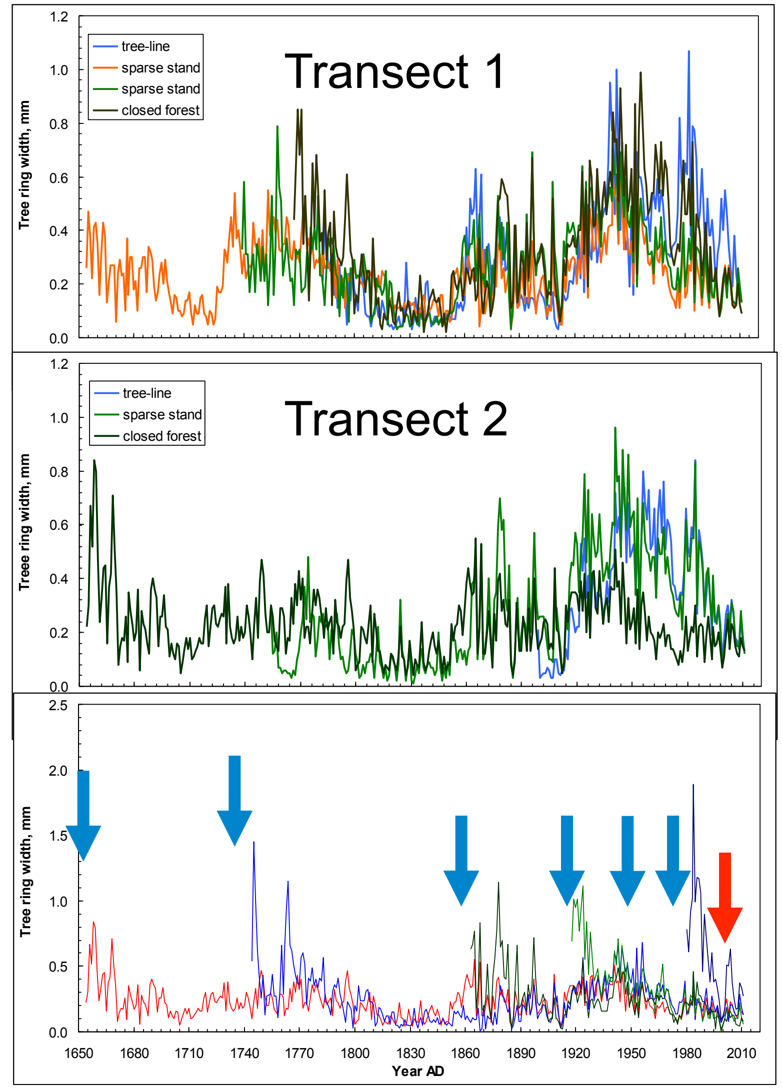
Periods of larger TRW correspond to new larch generation establishment

20th century showed 4 periods with good growth of stands and new tree generation establishment

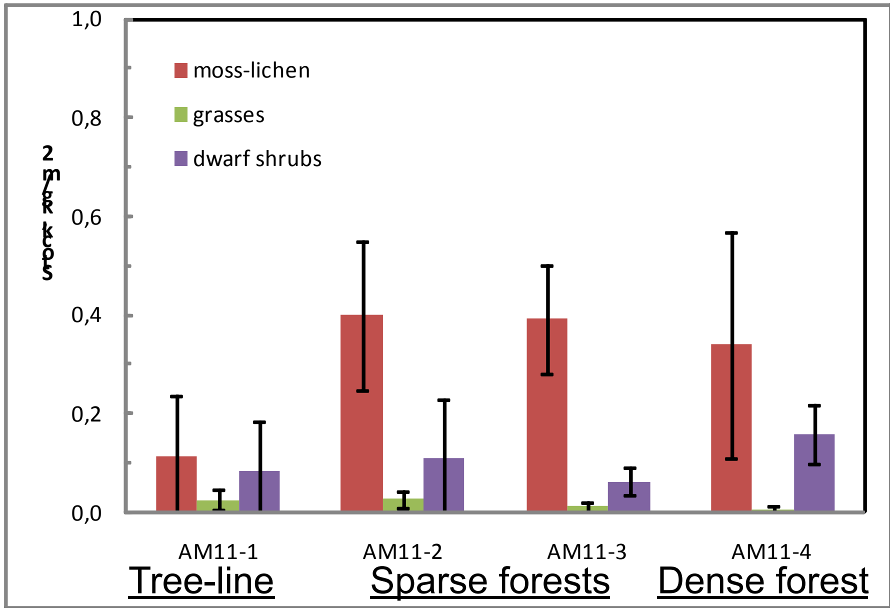
Better radial growth of tree generations established after 1940's

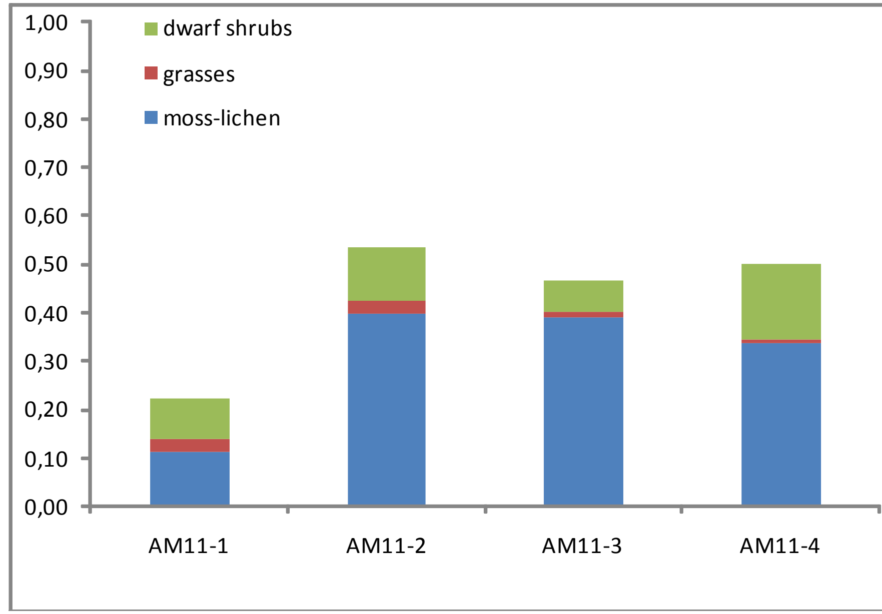
The latter generation (mid-1990's) does not reach 1.3 m height yet

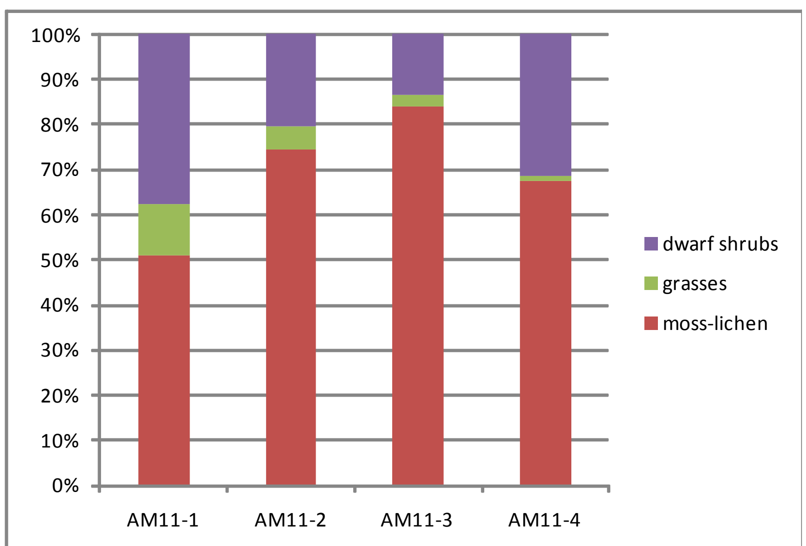




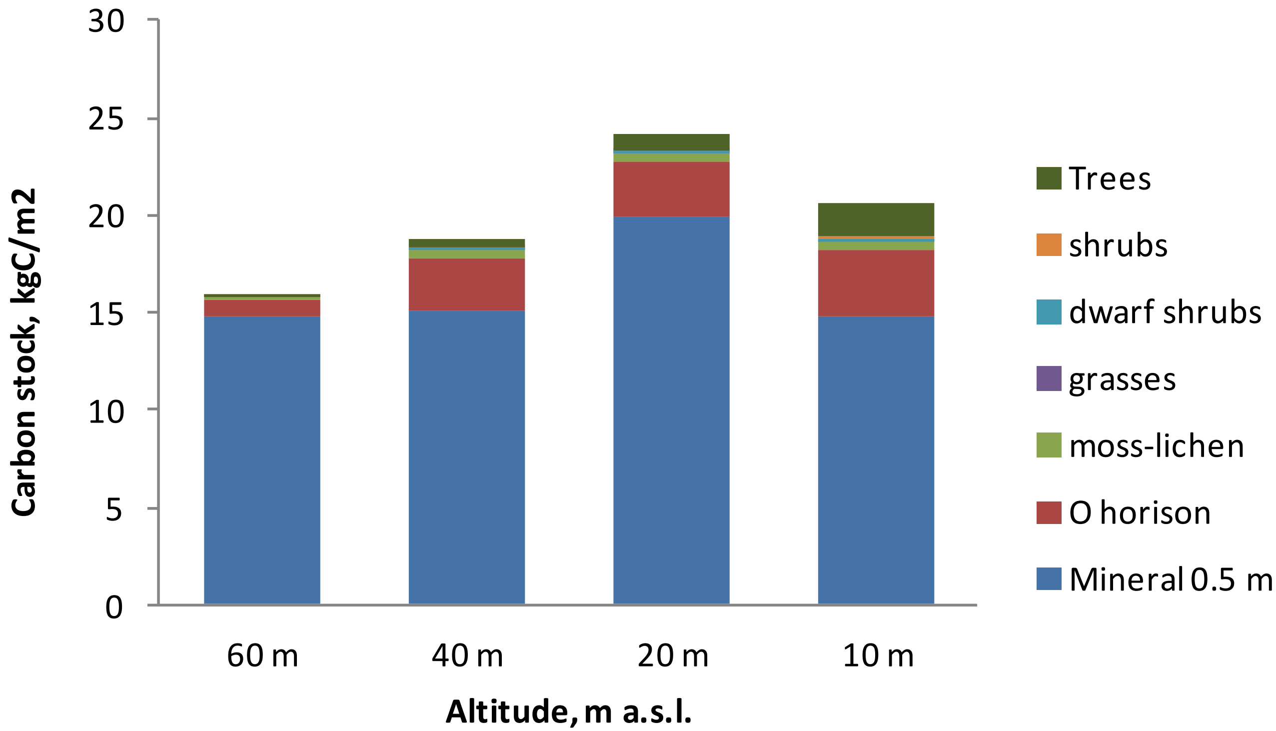
Ground vegetation

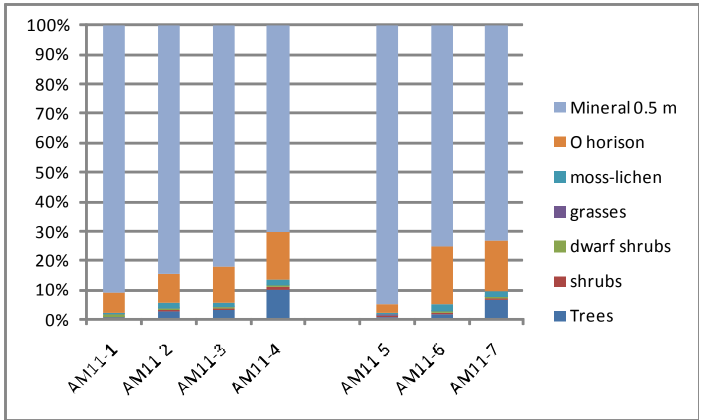




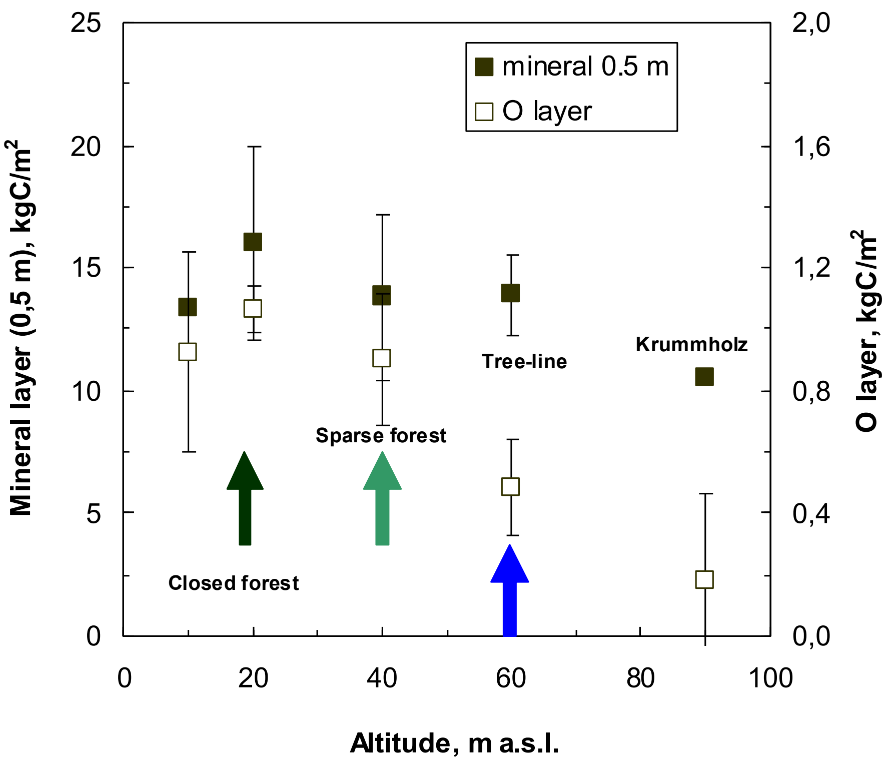


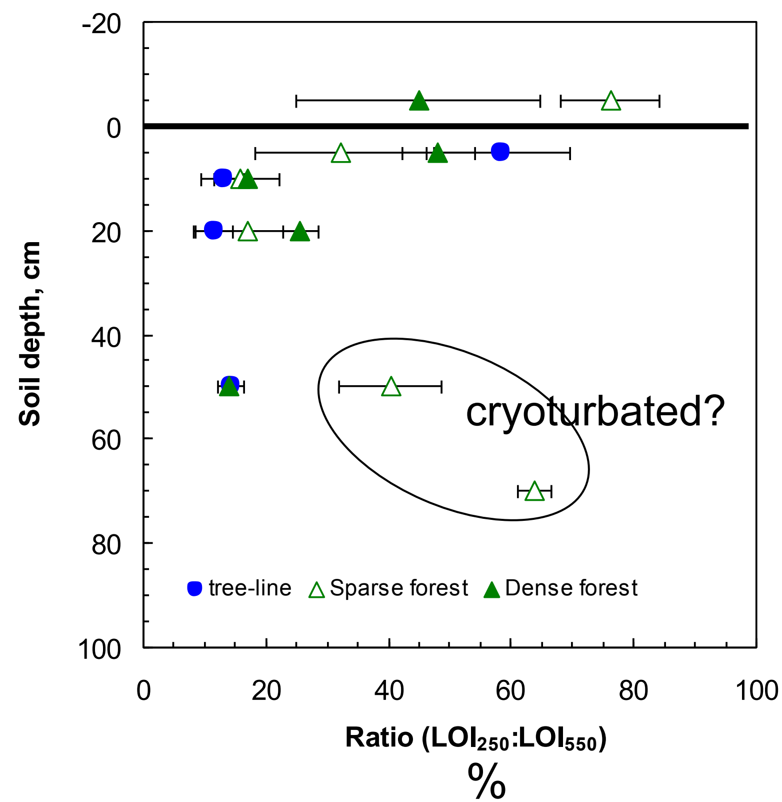
Carbon pools in ecosystems





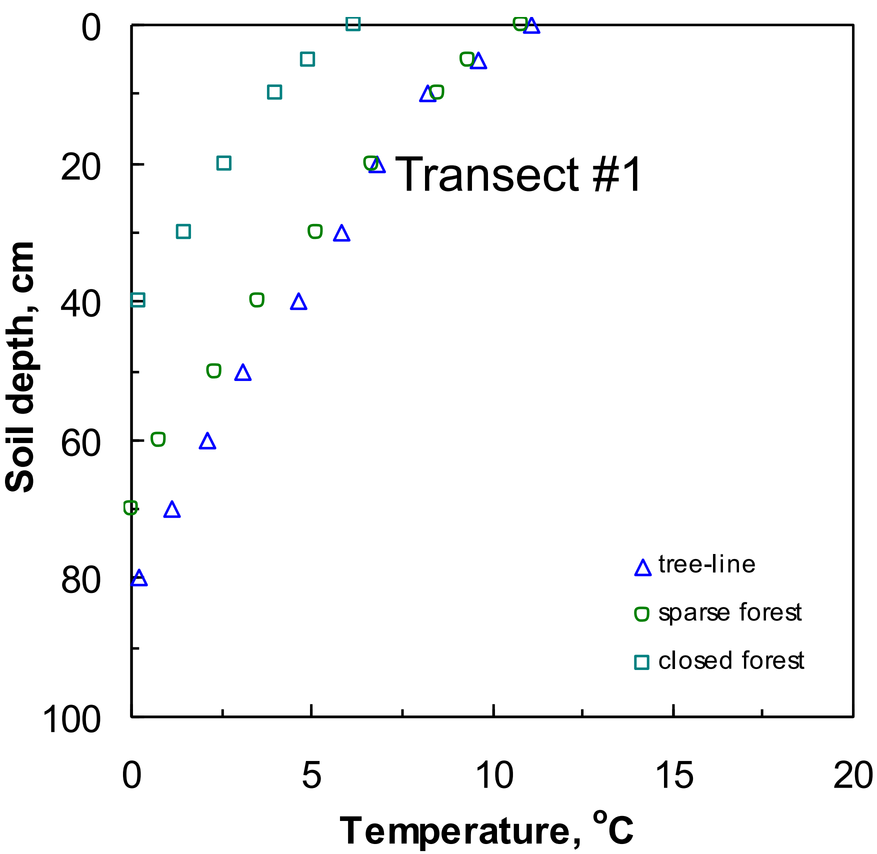
Soil organic matter

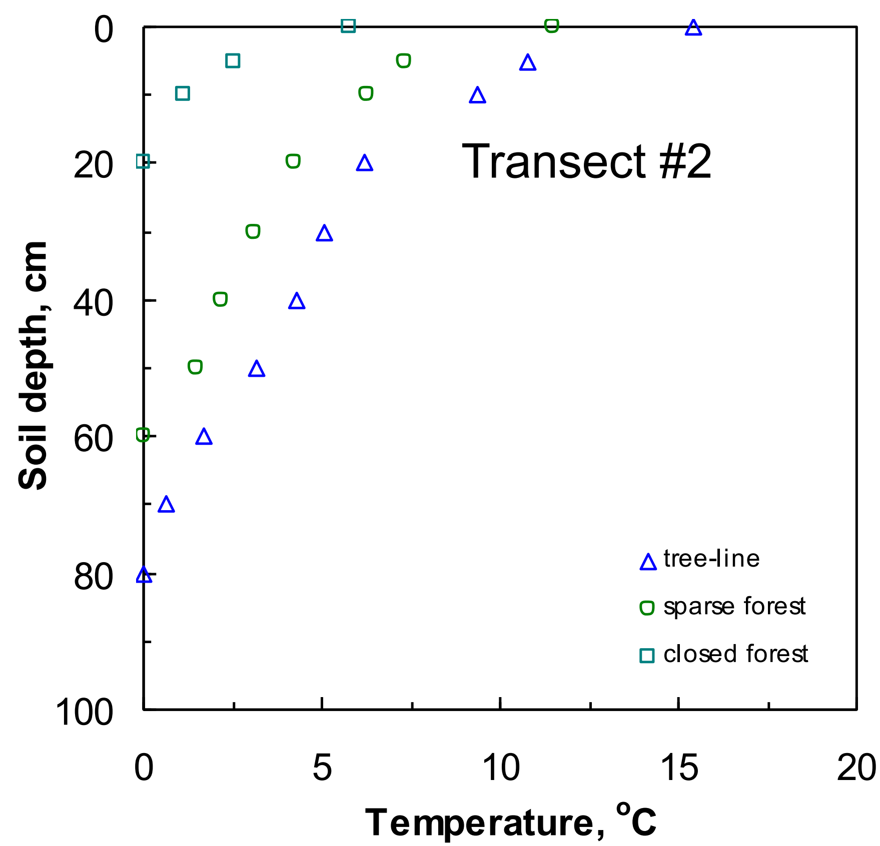




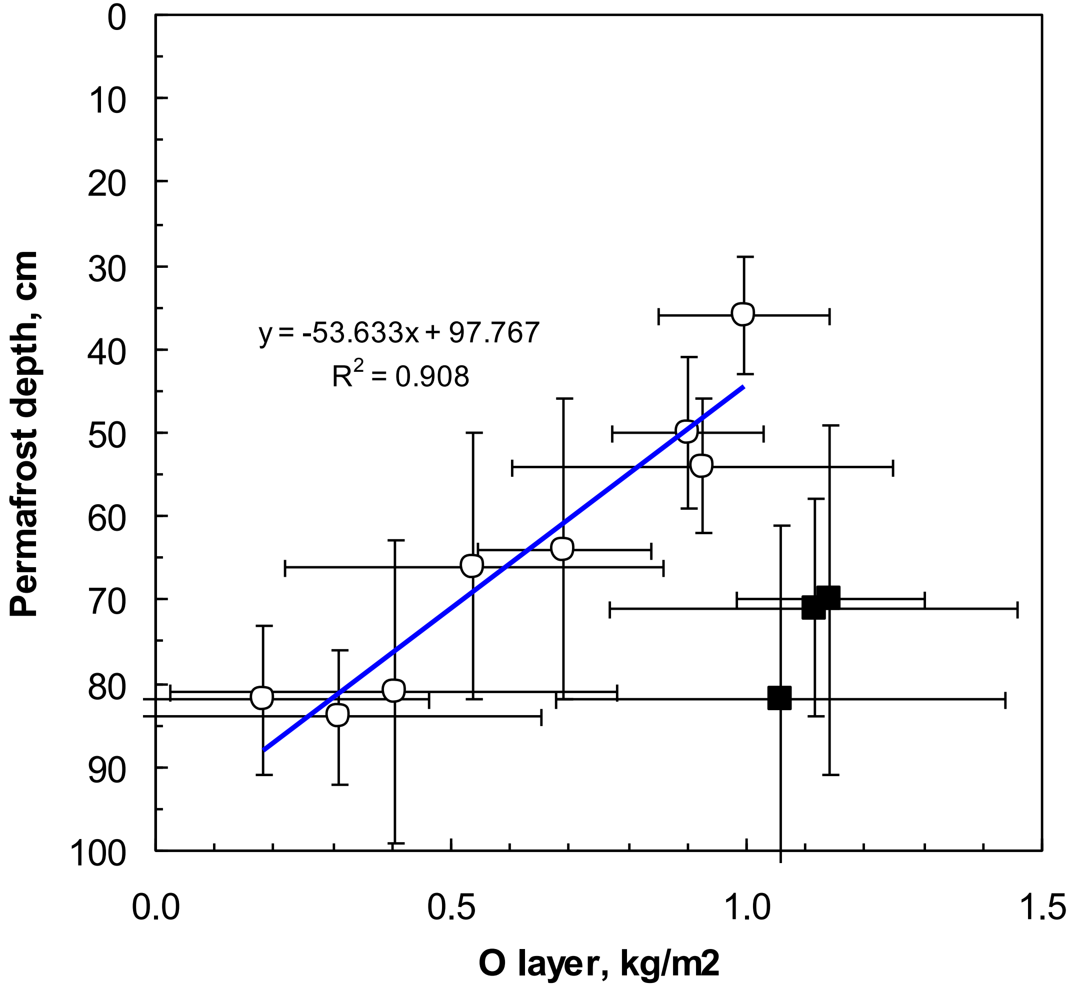
- Invasion of forest <u>has little effect on the C stock in 0.5 m layer of soil</u>
- Invasion of forest <u>leads to the accumulation of C in O layer</u>
- Forest SOM is less thermoresistant: in short-term perspective to analyze biodegradability in incubation experiment

Forest invasion (moss and O layer development) affects soil temperature

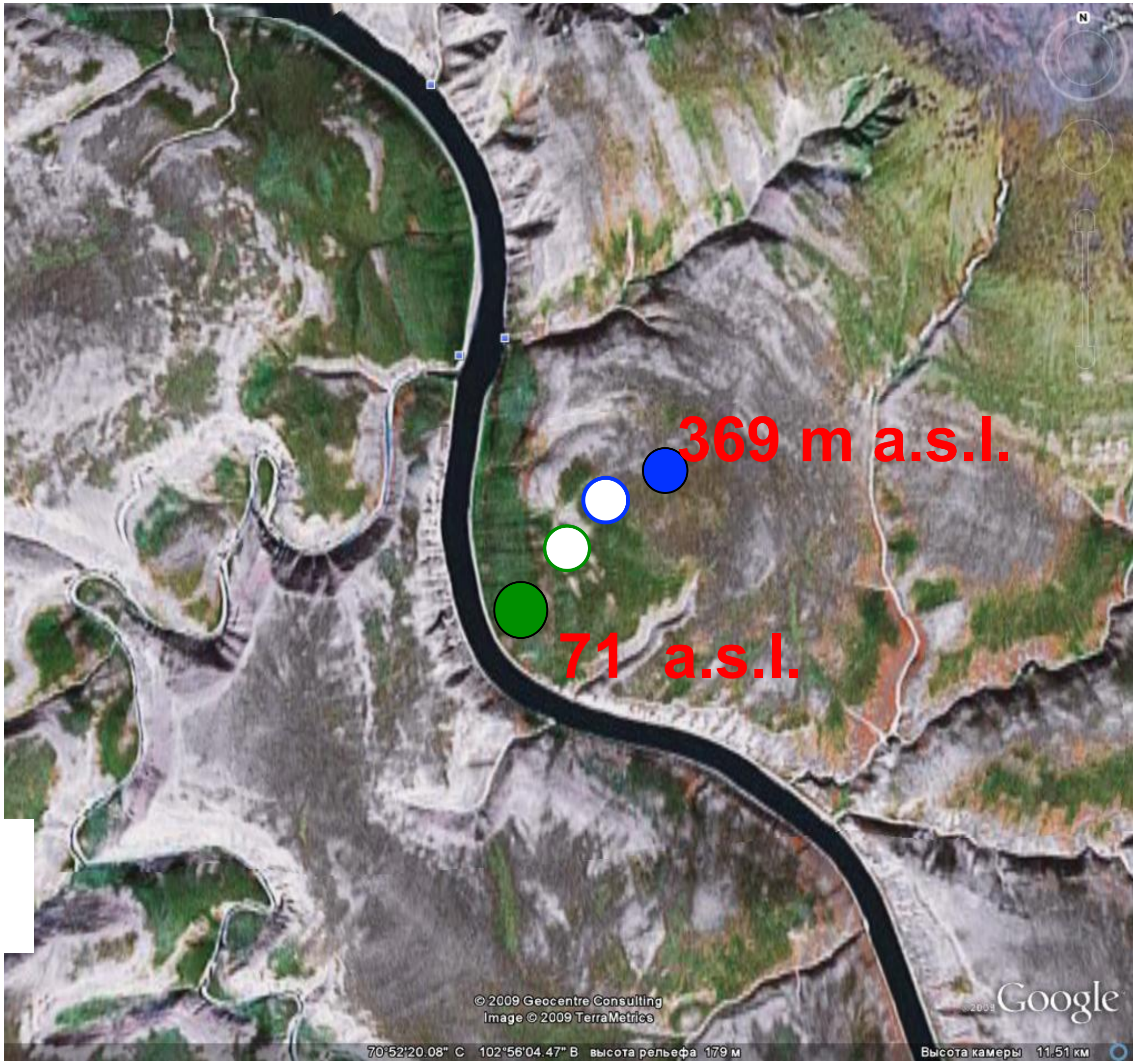




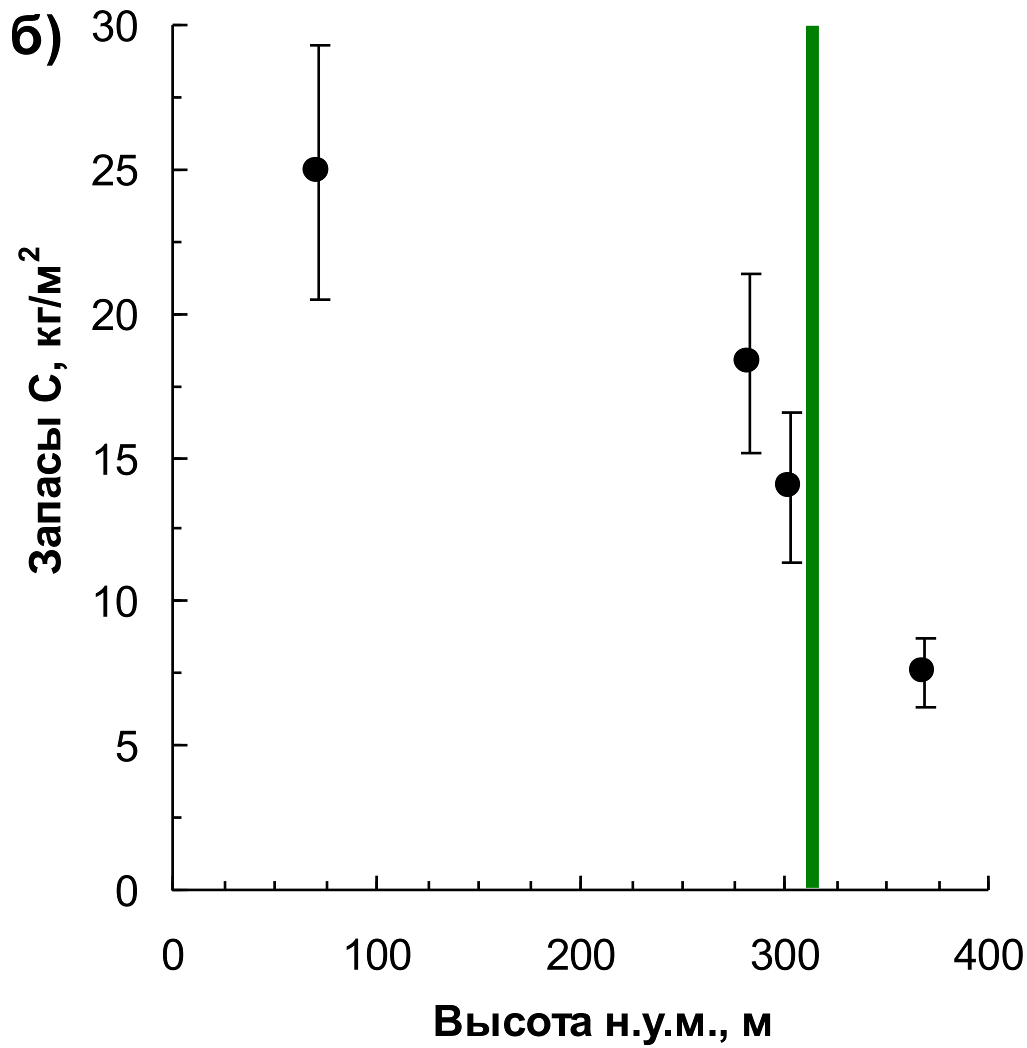
…and permafrost depth



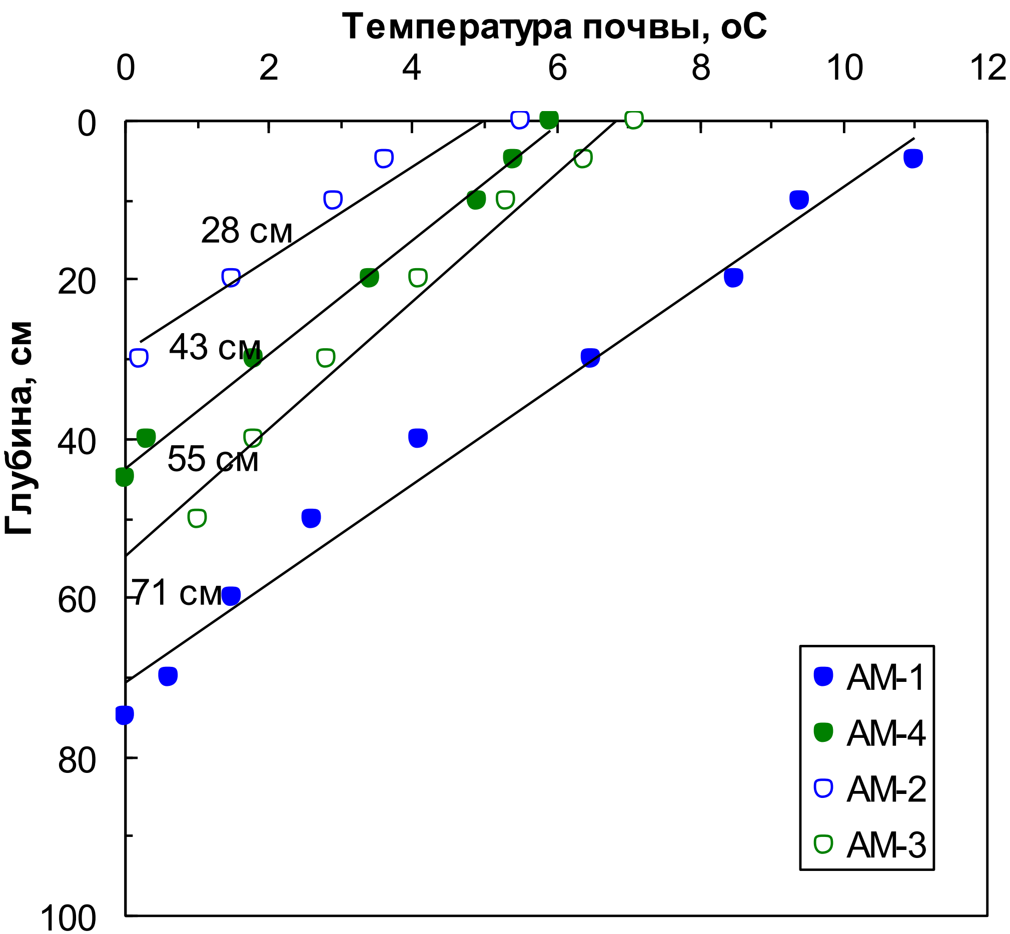
Tundra, tree-line and forests in Anabar plateau

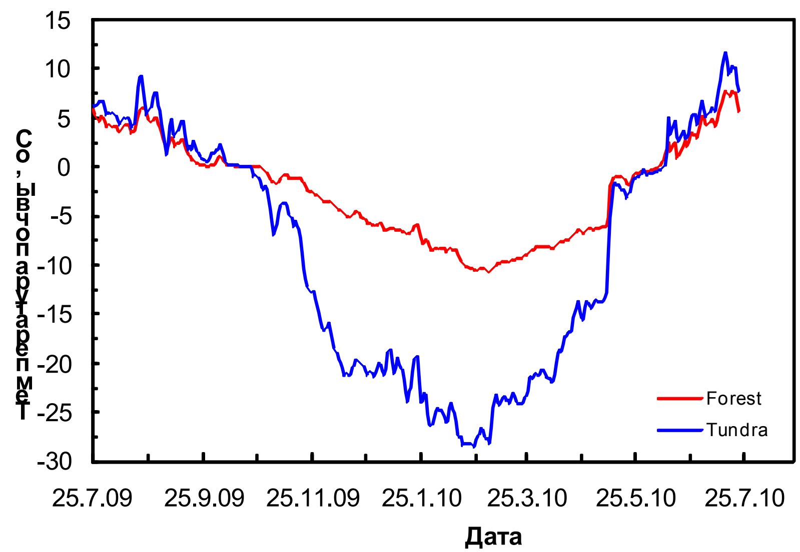


Soil C stocks

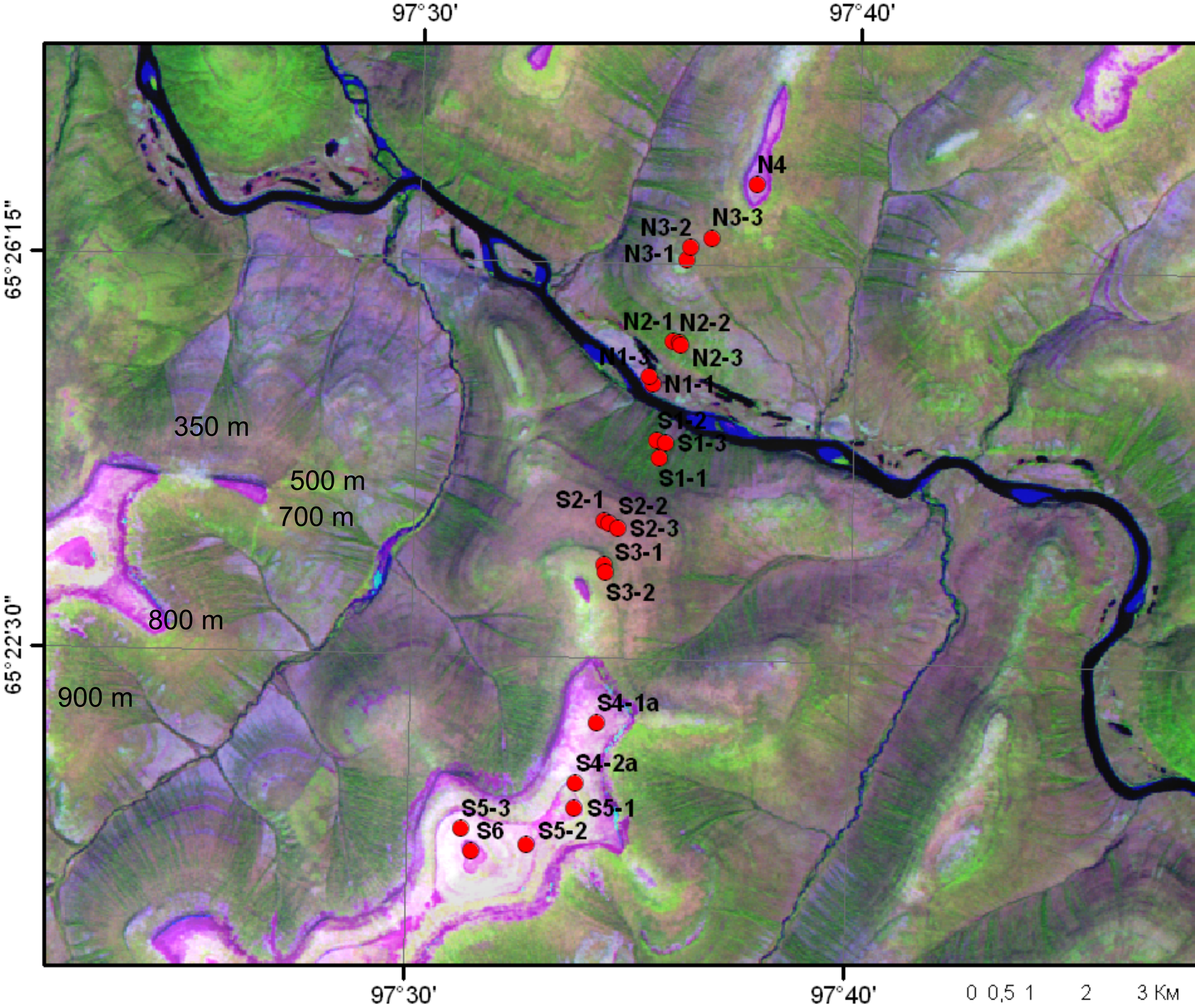


Soil Temperature

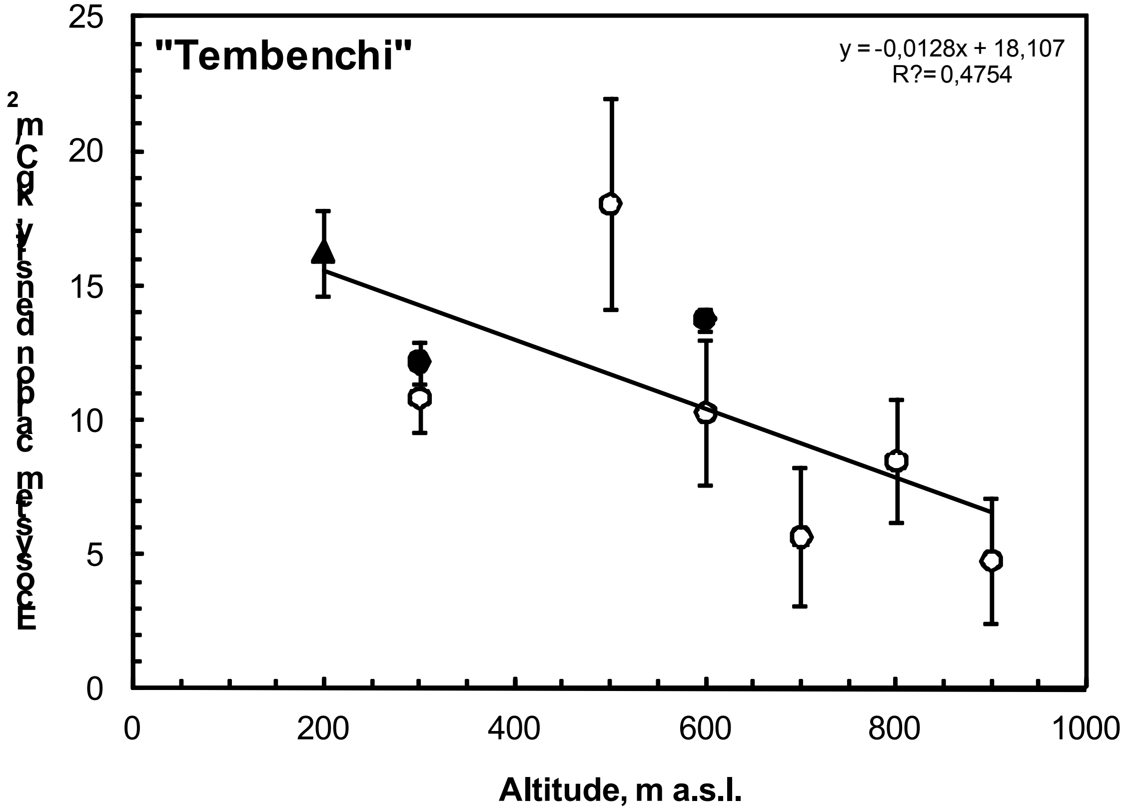


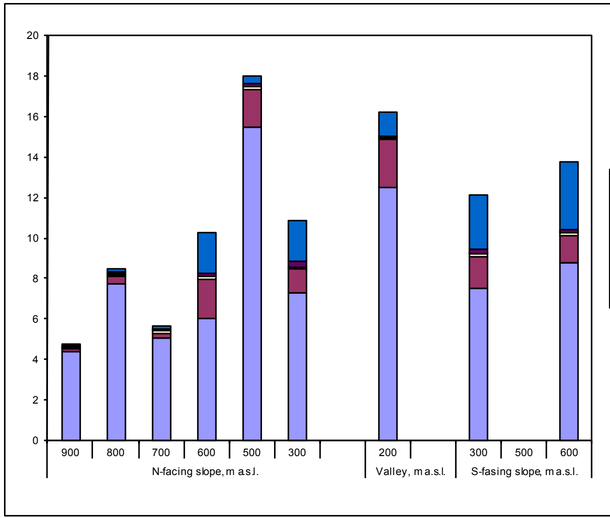


Tree-line and forests in Putorana Plateau

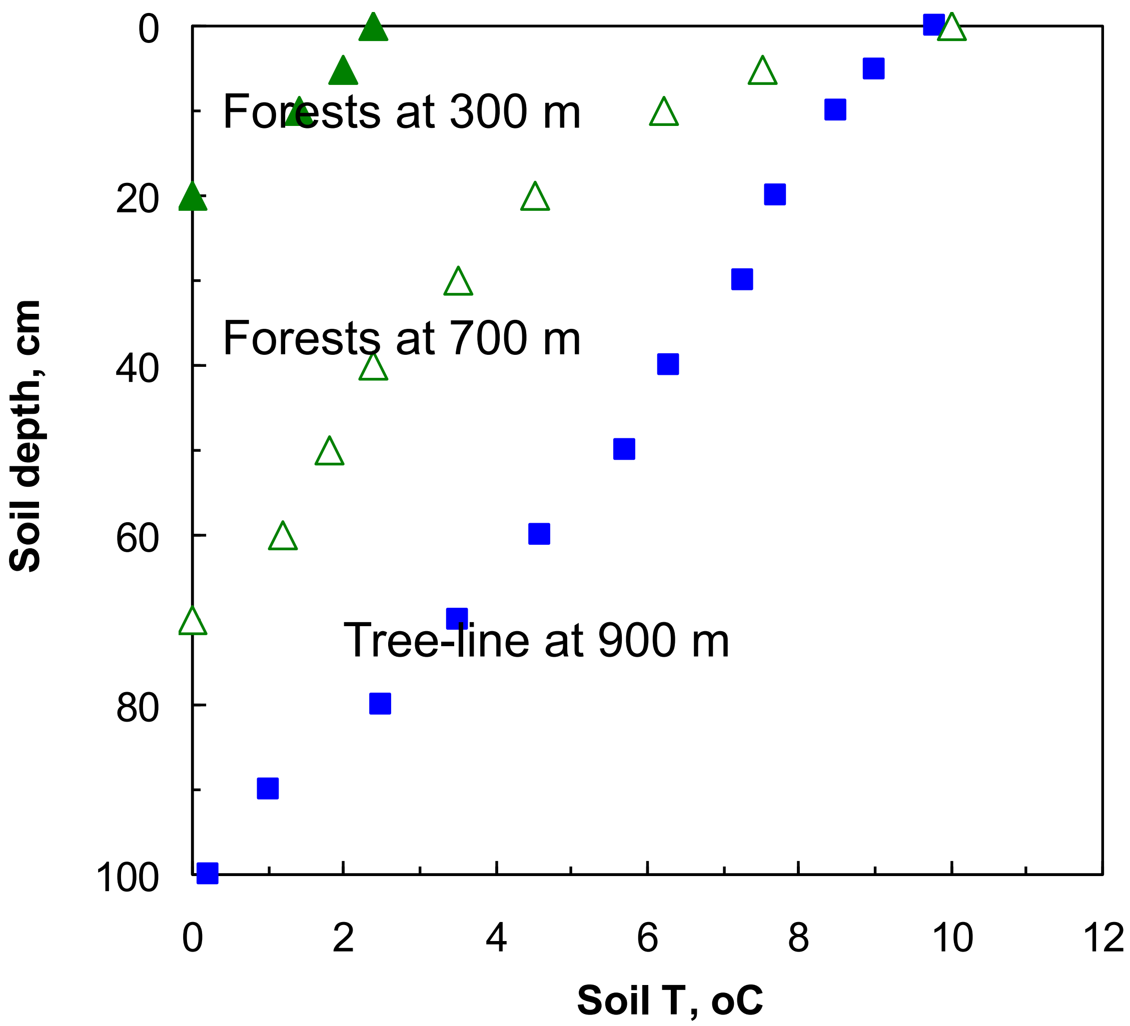


Ecosystem C stocks

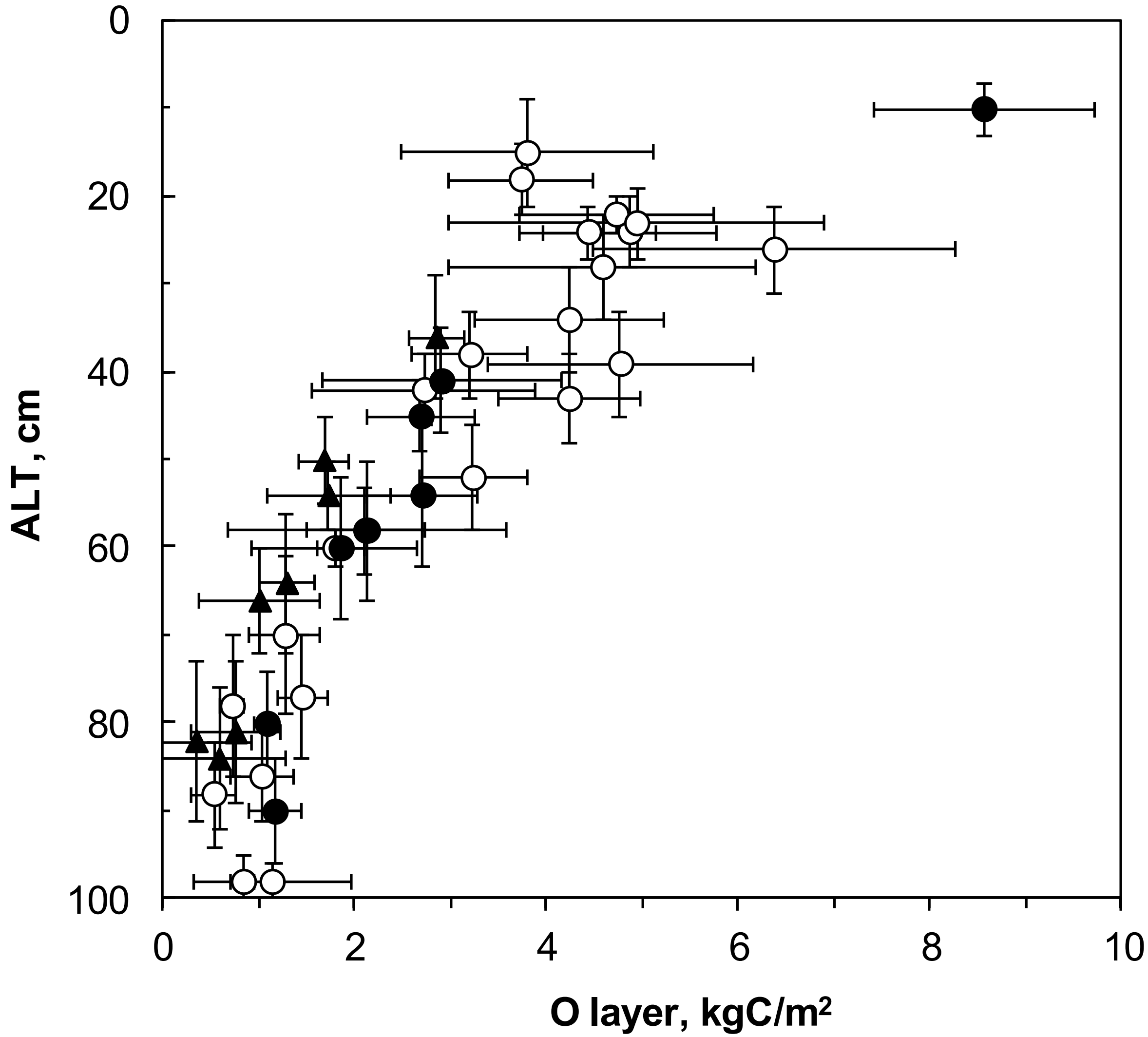




Soil Temperature



Organic layer stock vs. active layer thickness



“Forest” effects

- Changed plant species composition in ground vegetation (i.e. mosses replace grasses)
- Increased ground vegetation coverage

  (no or little frost boils);
- Enhanced O layer thickness

Causes:

- Canopy effect?
- Snow accumulation?
- Litterfall biochemistry?

Tundra soils: Carbon stock comparison

within top 100 cm (modified after Gundelweinet al., 2007 Eur. J. Soil Sci.)

Author(s)	Region	Number of profiles	Organic carbon kg OC m-2
Tarnokai& Smith (1992)	Canada	14	4 –63
Matsumura& Yefremov(1995)	Russia	7	11 –20
Batjes(1996)	Worldwide	5	16 –125
Ping et al. (1997, 2002)	Alaska	42	10 –94
Stolbovoi(2000, 2002)	Russia	<163	17
Post (2006)	Worldwide	–	14
Gundelweinet al. (2007)	Sibiria	10	31

within top 50 cm (depth estimate limited by shallow forest soils)

This study	**Central Siberia Tundra (tree-line)**	**7**	**4–16**
This study	**Central Siberia Forests**	**27**	**6-27**

CONCLUSIVE REMARKS:

1. Soil organic matter of present tundra ecosystems could be formed in forested terrain of past warm period in HOLOCENE;

2. Larch invasion to tundra and stand development patterns such as closed canopy, complete moss cover of ground surface and accumulation of O layer all induce the raise of permafrost and decrease of soil temperature, both resulting in conservation of C (including previously cryoturbated horizons) in frozen subsoil for “LONG” period of time.
3. Warming as predicted for 2°C (for 2060) may convert tundra and forest-tundra ecotone areas to northern Larix taiga, but still underlain by continuous permafrost.

Perspectives:

1. Carbon age, biomarker analysis, isotopic composition (C, N) of SOM and vegetation at latitudinal transect (Central Siberia: Ary-Mas … Baykit) and altitudinal transects at all 5 sites;
2. Biodegradability of SOM in incubation experiments;
3. Retrospective analysis of satellite data (NDVI) for 10 km belt near 102^{o}E from 71 to 73^{o}N to estimate “greening” of the area.

Acknowledgements

- RFBR and ESF for financial support
- Special thanks to all people assisted with field works and lab analyses


Thank you for attention!