Authors Reply

by Matthias Fuchs, on behalf of all Co-authors (matthias.fuchs@awi.de)

Authors response to Anonymous Referee #2

5   We thank the Anonymous Referee #2 for the valuable feedback which allows us to improve our manuscript. With this reply we hope to address all the comments and suggestion of the referee. Our changes and point-by-point replies are presented below.

Referee Comment (RC): *The authors of "Carbon and nitrogen pools in thermokarst- affected permafrost Landscapes in Arctic Siberia" have executed and interesting study and presented a well written*
10   *manuscript. The data are interesting and provide valuable measurements of permafrost C and N stocks. Some of the field sampling methods should be explained further to ensure the data merit scaling up using the landscape mapping approach described.*

Authors Reply (AR): Thank you for your positive feedback. We went through the field method sampling section and tried to improve it according to your suggestions. We hope to clarify with this reply the open questions.

15   **RC**:   *The inclusion of N pools in this manuscript represent a novel contribution to the field of permafrost mapping but the implications for the author's findings should be more fully developed in the discussion.*

AR: This is a valuable suggestion and we included an additional paragraph in the discussion about the role of nitrogen in a thawing permafrost environment.

RC: *Details regarding the analysis of soil samples for %N must be clarified as well- the low N content of these mineral*
20   *soils suggests that separate analysis for %C and %N would be necessary given the limitations of most elemental analyzers.*

AR: We did not run separate analyses for %C and %N. For the elemental analysis we homogenize and grinded the sub-samples thoroughly prior to measuring. Also, the elemental analyser does not measure the absolute weight of an element but through combustion and gas separation the peak flow of N2 and CO2 are detected and converted to the
25   absolute weight of the element based on the calibration.

RC: *PG3, Line 11-15: Koven's study did an excellent job comparing two potentially limiting factors on ecosystems carbon balance (SOM-C decomposability, plant N limitation) but it doesn't present a strong argument against plants accessing N in newly thawed permafrost. They assume aboveground plant phenology reflects belowground plant phenology and say that they do not capture the microbial community/decomp dynamics observed in manipulative field*
30   *experiments with the simplified N cycle they included in CLM. There is a growing body of field studies looking at plant access to N from thawing permafrost- Keuper et al 2017 (Global Change Biology) and references herein would be a good place to start.*

AR: Thank you for the clarification. We removed Koven et al. (2015) from the introduction and added the suggested reference instead. We included a paragraph in the discussion about the potential offset of carbon release by the increased availability of nitrogen and increased biomass.

RC: *PG3, Line 30: The introduction should include background information and literature references regarding the CN ratio of permafrost soils and how it relates to the past and future decomposition of SOM (ie, Schaedel et al 2014, Global Change Biology). The addition of N pool data is interesting component of this paper but seems underexplored.*

AR: This is right and we agree that we did not cover the CN ratio in the introduction so far. We included now one additional paragraph in the introduction with background information regarding the CN ratio. In particular we moved PG14, Line 12-17 into the introduction as the referee suggested.

RC: *PG5, Line 20-31: The field methods should be clarified to ensure the data represent the landscape adequately and will bear the scaling approaches utilized. How can the sampling point locations be equidistant from one another along a transect and reflect a stratified sample scheme? Does "stratified sampling" refers to the choice of transect location? How were the number of samples from baydzherakhs decide? What landscape features were baydzherakhs and DTLB data points grouped with for the average %C and %N values given in Table 1?*

AR: The sampling approach is stratified in the sense, that we chose the start location of the transect, the direction and the distance between the points. Randomness is included by the fixed distance between the sample points. The decision of the starting point and which landform types we want to cover with our transect is therefore stratified. Baydzherakhs are a common but rather small feature in the study area. Due to the transect approach and the points equidistant from each other, we did not end up on a baydzherakh in two transects. On one of those transects (SOB14-T1) there were no baydzherakhs in the surroundings, on the other transect (SOB14-T2) we additionally sampled a baydzherakh in close proximity to the transect. On another transect on Bykovsky Peninsula (BYK14-T2) we chose a baydzherakh as a starting point. Baydzerakhs represent polygon centres; since we want to drill permafrost soil cores it is imperative to drill in polygon centres and baydzherakhs a perfect example for this. With the transect approach, we sampled different Yedoma upland sites, however due to an ice wedge content of 40 – 44 % in the landscape, we sometimes hit ice-wedges while sampling. The baydzheraks are seen as additional sampling sites on transects where they occurred. However, even for a RapidEye based upscaling, these features are too small to be resolved in a landform classification. Baydzherakhs were grouped into the Yedoma upland class and DTLB data points were grouped into the thermokarst class in Table 1.

RC: *PG6, Line 9-13: Were separate samples run for %C and %N analysis?*

AR: The TC and TN measurements are measured in one run. Just TOC is measured separately with another device. However, each sample was measured with two replicates and we allow a deviation < 5% between the two measurements. If this criterion is not fulfilled, we repeat the measurements until our data quality criterion is met. All lab data is checked by the laboratory leads before the data is released.

We included the information that we measure in one run but do double measurements in chapter 2.3.

RC: A larger weight of sample might have been necessary to determine %N numbers, especially on these mineral soils. A 5mg sample with only 0.1% N (Table 1 data) for instance would only have 5ug N which is likely below the detection limit for many elemental analyzers. Please provide detection range and sensitivity for this machine and/or specify sample amounts for the separate analyses if indeed samples were run separately.

AR: A larger weight of the samples might increase the accuracy of the measurements in case of very low percentages. However, the elemental analyser does not measure the absolute weight or percentages but it combusts the sample and measures the peak flow of N_2 and CO_2 (in mV) and then calculates the %C and %N based on the calibration, the integral of the peak flow and the initial weight of the sample. Also, we annually calibrate the device in accordance with Elementar Analysesysteme (the manufacturer of the device). This calibration determines the maximum and minimum threshold for the measurements and therefore determines the minimum detection limit which is approximately three times above the measured noise (personal communication with Elementar Analysesysteme). We start each measurement run with 8 standards (EDTA, IVA) for determining the daily factors of C and N. This is followed by another 8 control standard samples (EDTA, IVA, soil standards). This control group is always included after 30 measured samples as well as in the end of each measurement run. With this procedure we can check the accuracy and detect potential imprecisions during the measurement. Prior to the measurement we homogenize the samples by grinding thoroughly. We measure two replicates of each sample and allow a <5% deviation for our double measurement. The device gives percentage values if the measurement is in the detection range. Otherwise an error is reported. The sensitivity of the Vario EL III is <0.1%.

RC: *PG7, thoughout: Please clarify how ground-truthing was conducted. Were training areas selected based on observations made in the field? Did any of the field observations points overlap with the high-resolution imagery described to check landform classification?*

AR: The high resolution images do overlap with the sites sampled in the field. However, field time, as usually, is limited and our field-based ground truth sites had to be complemented by ground truth points characterize with very high-resolution imagery, with which it was possible to differentiate between the different landform types as well as water areas. Such mixed ground truth approaches have been successfully applied before in areas with limited field data. Further a digital elevation model helped to identify partly degraded Yedoma uplands. The training areas for the land cover classification were chosen based on the field reconnaissance (PG7 Line 22). Another sentence about the overlapping of the high-resolution satellite imagery with the sampled field sites was added.

RC: *PG8, Line 4-8: Somewhat confusing to have this discussion of ice wedge calculations when the reader does not yet know the source of ice wedge content data... consider moving to later in the methods section.*

AR: We removed the ice wedge calculation part from this paragraph and mentioned it in the subsequent paragraph together with the ice wedge content data.

RC: *PG8, Line 27: Is the difference described here significant? Seems unlikely given the variation in the Bykovsky samples.*

AR: The difference is statistically significant (student t-test; $p<0.01$). However, in an earlier review phase, we decided to keep the manuscript descriptive.

RC: *PG14, Line 12-17: Move this background info to Introduction.*

AR: Changed as suggested. See comment above on PG 3 line 30.

RC: *Would it be possible to use the C:N data in this paper to estimate C losses from these sites using the models in Schaedel et al. 2014? Some more developed discus- sion of potential N mineralization with decomposition of these soils would be warranted. This paper's inclusion of N stocks is novel but the discussion does not delve into the implications of the results.*

AR: According to Schädel et al. (2014), the % initial C in combination with the CN ratio can be an indicator for the potential C loss over time. However, the scope of the paper was not the determination of C release but the estimate of C pools across different depth intervals in a thermokarst landscape. Hence, detailed modelling would go too far for this study but could be envisioned in the future. We added a paragraph on nitrogen which becomes available upon permafrost thawing and its potential effects on biomass production and carbon release offset in the discussion chapter 4.1.

RC: *Table 1: Please include symbols or alternate font styles to denote statistical differences between sites and landscape forms.*

AR: In a previous review phase we decided to keep the manuscript descriptive, since this was suggested by the editor.

RC: *Figure 2: Model summaries for decreasing C:N with depth and summary statistics should be included here.*

AR: The correlations of a decreasing CN with depth are added to the graph. The mean CN for active and permafrost layer are mentioned in the text on page 9, line 12-15.

References:

References:

Keuper, F. et al. (2017): Experimentally increased nutrient availability at the permafrost thaw front selectively enhances biomass production of deep-rooting subarctic peatland species, Glob. Change. Biol., 23, 4257-4266, doi:10.1111/gcb.13804.

Schädel, C., et al. (2014): Circumpolar assessment of permafrost C quality and its vulnerability over time using long-term incubation data, Glob. Change Biol., 20, 641-652, doi:10.1111/gcb.12417.

Authors response to Anonymous Referee #3

We thank the Anonymous Referee for the positive feedback on our manuscript and the valuable comments. We have gone through your comments and improved our manuscript according to your suggestions. Also, we uploaded the data in the PANGAEA data repository and will provide a doi link in the final version of our manuscript. We hope to address with this reply all your suggestions and questions. Our changes and point-by-point replies are presented below.

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Referee Comment (RC): *Fuchs et al present analyses of soil carbon and nitrogen stocks across a range of representative landforms for two study areas in the Lena River Delta in northern Siberia. These areas are underlain by ice rich Pleistocene age yedoma permafrost, which is poorly represented in pan-Arctic inventories. The study quantifies variability within and between landforms, and uses high resolution multispectral and DEM data to create a landscape*

10 *classification used for up-scaling soil carbon and nitrogen stocks. The methods of sampling and analyses are conventional, and executed well. The results are in line with other studies in that higher carbon and ni- trogen stocks are found in yedoma soils. These results help improve understanding of landscape variability in permafrost soil properties. The nitrogen stocks are particularly useful, as these data are not often analyzed or reported.*

Authors Reply (AR): We thank the referee for this positive feedback and acknowledging the importance of our study.

15 **RC**: *I do wonder if the data are open access, and if so, the authors should post a link to the repository or include a data citation with doi. This is becoming increasingly common, and this is a good thing. These data are valuable, especially given the remote location and importance of the data. The summaries in the supplement are a good start, but tabular data in a slightly more raw form would be good.*

AR: We submitted the data to the PANGAEA data repository (www.pangaea.de). With the following link the data is

20 accessible: https://doi.pangaea.de/10.1594/PANGAEA.883582

We submitted the data from Table 1 from the manuscript, the sample site characteristics, the carbon and nitrogen data presented in the supplement material, as well as the radiocarbon data to the PANGAEA data repository. We included the following statement below the conclusion:

Supplementary data are available at https://doi.pangaea.de/10.1594/PANGAEA.883582

25 **RC**: *P3 L5: See also Webb et al 2017 – this is a recent citation and may be relevant here and in the discussion.*

AR: Thank you for the suggestion. We included this citation in the introduction and added a sentence in the discussion.

RC: *P3 L13: Perhaps cite Abbott et al 2016 here – I'm not sure that NPP increases will offset permafrost SOC emissions, even with increased N availability.*

AR: We changed this part of the introduction slightly according to referee #2. Though, we included the suggested reference

30 in the discussion.

RC: *P3 L23: I don't think DTLB has been defined yet.*

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AR: Yes you are right, thank you for the hint. We included the definition of this abbreviation in the sentence on P3 L20-24.

RC: *P9 L28-29: This statement is unclear – do you mean to say that a single core is affecting the mean? Please clarify.*

AR: For thermokarst on Bykovsky Peninsula we only have one core (BYK14-T3-3) reaching a depth of two meters. Therefore, the mean for 0-200 cm is based on this single core only (see Fig. 3). This core was very carbon rich compared to the other cores (see Table S4) from thermokarst sites and therefore the high carbon storage for thermokarst in 0-200 cm need to be interpreted carefully. We added the following sentence in the manuscript on P10 L7: "However, this estimation is only based on one relatively C rich core (BYK14-T3-3), since this is the only core reaching a depth of two meters for thermokarst on Bykovsky Peninsula. Therefore the carbon estimation for thermokarst on Bykovsky Peninsula for the soil interval 0-200 cm has to be interpreted carefully."

RC: *P32-33: In figures 3 & 4 it would be good to have an outline around the key for the striped bars.*

AR: Changed as suggested C3

References:

Abbott, B. W. et al. (2016), Biomass offsets little or none of permafrost carbon release from soils, streams, and wildfire: an expert assessment, Environ. Res. Lett., 11(3), 1–13, doi:10.1088/1748-9326/11/3/034014.

Webb, E. E. et al. (2017), Variability in above- and belowground carbon stocks in a Siberian larch watershed, Biogeosciences, 14(18), 4279–4294, doi:10.5194/bg-14-4279-2017.

We thank the two Anonymous Referees for their constructive comments and suggestions which allow us to improve our manuscript. In the following the manuscript including all changes is added.

On behalf of all the Co-authors

Matthias Fuchs

Carbon and nitrogen pools in thermokarst-affected permafrost landscapes in Arctic Siberia

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Abstract. Ice rich Yedoma-dominated landscapes store considerable amounts of organic carbon (C) and nitrogen (N) and are vulnerable to degradation under climate warming. We investigate the C and N pools in two thermokarst-affected Yedoma landscapes – on Sobo-Sise Island and on Bykovsky Peninsula in the North of East Siberia. Soil cores up to three meters depth were collected along geomorphic gradients and analysed for organic C and N contents. A high vertical sampling density in the profiles allowed the calculation of C and N stocks for short soil column intervals and enhanced understanding of within-core parameter variability. Profile-level C and N stocks were scaled to the landscape level based on landform classifications from five-meter resolution, multispectral RapidEye satellite imagery. Mean landscape C and N storage in the first meter of soil for Sobo-Sise Island is estimated to be 20.2 kg C m^{-2} and 1.8 kg N m^{-2} and for Bykovsky Peninsula 25.9 kg C m^{-2} and 2.2 kg N m^{-2}. Radiocarbon dating demonstrates the Holocene age of thermokarst basin deposits but also suggests the presence of thick Holocene aged cover layers which can reach up to two meters on top of intact Yedoma landforms. Reconstructed sedimentation rates of 0.10 mm yr^{-1} - 0.57 mm yr^{-1} suggest sustained mineral soil accumulation across all investigated landforms. Both Yedoma and thermokarst landforms are characterized by limited accumulation of organic soil layers (peat).

We further estimate that an active layer deepening by about 100 cm will increase organic C availability in a seasonally thawed state in the two study areas by ~5.8 Tg (13.2 kg C m^{-2}). Our study demonstrates the importance of increasing the number of C and N storage inventories in ice-rich Yedoma and thermokarst environments in order to account for high variability of permafrost and thermokarst environments in pan-permafrost soil C and N pool estimates.

1 Introduction

Yedoma regions store large amounts of soil organic carbon (SOC) and are highly vulnerable to permafrost thaw under climate warming (Zimov et al., 2006, Strauss et al., 2013). Organic C, freeze-locked for millennia in these permafrost deposits, may become available for increased microbial activity and release in the form of the greenhouse gases CO_2 and CH_4 after thaw (Gruber et al., 2004; Tarnocai, 2006; Dutta et al., 2006, Schuur et al., 2008; 2015). Carbon-rich Yedoma regions therefore

have the potential to contribute significantly to greenhouse gas emissions in a rapidly warming Arctic (Schneider von Deimling et al., 2015).

      The term Yedoma describes late-Pleistocene, ice-rich, silty deposits covering vast areas in the northern permafrost regions that were not glaciated during the last ice age (Schirrmeister et al., 2011a; 2013). These deposits can reach a thickness
5 of up to 50 m, store large amounts of C, and are still present today in an area of approximately 625,000 km^2 in the Siberian and North American permafrost region (Strauss et al., 2017). Since deglacial warming, large areas of the former Yedoma surfaces, expanding across several million km^2 of North and East Siberia, Alaska, Northwest Canada, and the adjacent shelf regions, were eroded by thermokarst processes. These processes affected the landscape by permafrost thawing and ice wedge melting leading to surface lowering, lake formation, and lake drainage. Resulting landscape features include thermokarst
10 mounds (also called baydzherakhs), thermo-erosional gullies, thermokarst lakes, and thermokarst depressions (drained thaw lake basins or alas) which now are dominant features in the Yedoma terrain (Jorgenson and Shur, 2007; Veremeeva and Gubin, 2009; Kokelj and Jorgenson, 2013, Morgenstern et al., 2013, Ulrich et al., 2014).

      Ice rich Yedoma and thermokarst deposits are prone to thaw after disturbances that change the surface thermal regime (e.g. from changing air temperatures, fire, or anthropogenic disturbances). Since Yedoma as well as thermokarst deposits
15 contain large, potentially vulnerable C pools in permafrost regions (Zimov et al., 2006; Strauss et al., 2013; Walter Anthony et al., 2014) they are of global importance for SOC accumulation, degradation, and release. Whereas degrading Yedoma surfaces and thermokarst features lead to thaw-induced remobilization of organic C, the drainage of thermokarst lakes and the following permafrost aggradation lead to SOC accumulation and stabilization (Hinkel et al., 2003; Jorgenson and Shur, 2007; Jones et al., 2012; Grosse et al., 2013). Olefeldt et al. (2016) estimated that landscapes potentially vulnerable to thermokarst
20 contain up to 50% of the total SOC stored in the permafrost region. In the Yedoma region, 60% of the C is stored in drained and refrozen thermokarst basins (Strauss et al., 2013). However, these estimates are based on few data points from the Yedoma region and it remains important to enhance our understanding of the C storage, distribution, and vulnerability in these environments with detailed landscape-scale assessments.

      Several permafrost C pool estimates have been carried out from different areas within the Arctic region (e.g.
25 Michaelson et al., 1996; Kuhry et al., 2002; Ping et al., 2008; Tarnocai et al., 2009; Horwath Burnham and Sletten, 2010; Hugelius et al., 2010, 2011; Fuchs et al., 2015; Siewert et al., 2015; 2016; Palmtag et al., 2016). A synthesis for the circum-Arctic by Hugelius et al. (2014) merged a large number of datasets into the Northern Circum-polar Soil C Database (NCSCD) resulting in an estimate of 1035 ± 150 Pg of organic C for 0-3 m for soils in the permafrost region. Several additional estimates for SOC storage in the Yedoma region exist, some of which are taking into account slightly different components of the
30 Yedoma region. Zimov et al. (2006) calculated 450 Pg C for the C pool for the entire Yedoma region (including both Yedoma and thermokarst deposits). Walter Anthony et al. (2014) estimated the total Holocene and Pleistocene soil C pools of the Yedoma region with 429 ± 101 Pg C, while Hugelius et al. (2014) calculated 181 ± 54 Pg C for all deposits in the Yedoma region below three meter depth and Strauss et al. (2013) calculated 211 + 160/-153 Pg C for the entire Yedoma deposits including the top three meters. Despite the variation in these estimates they all suggest a very large C pool of several hundred

Pg for this region and confirm that these ice-rich deep deposits are a globally important C pool in the northern circumpolar permafrost region. Detailed local studies for particular parts of the Yedoma region are scarce so far but suggest significant landscape-scale and inter-regional variation in SOC stocks that warrant further local studies and regional syntheses (Schirrmeister et al., 2011b, 2011c; Strauss et al., 2012; Siewert et al., 2015, 2016; Shmelev et al., 2017, Webb et al. 2017).

5   However, the Yedoma and thermokarst landscapes not only host important C pools but potentially store a significant amount of N. Even though there are several permafrost soil C studies, only very few report N stocks (Ping et al., 2011; Harden et al., 2012; Michaelson et al., 2013; Zubrzycki et al., 2013; Obu et al., 2015, Palmtag et al., 2015). In tundra environments N often is the limiting factor for plant growth (Shaver et al., 1986; Chapin et al., 1995; Mack et al., 2004; Beermann et al., 2015). As a result, thawing permafrost not only has the potential to release large amounts of organic C but also to increase the
10 availability for N which may increase primary production and ~~partly~~ offset increased greenhouse gas emissions from permafrost soils (e.g. Keuper et al., 2012, 2017; Natali et al., 2012, Salmon et al., 2016). ~~Also, Keuper et al. (2017) reports that thawing permafrost poses an additional N source and increases the plant biomass production of subarctic Peatlands. Koven et al. (2015) reports that near surface N released from thawing permafrost might reduce nutrient limitations, even though the same study shows limited importance of the deep soil N to offset deep C release.~~

15   A potential indicator for the potential C loss upon thaw and the decomposability of C stored in permafrost soils is the carbon-nitrogen (CN) ratio (Schädel et al., 2014). ~~The CN ratio provides a first indication of the potential degradability of C stored in permafrost soils (Kuhry and Vitt, 1996; Hugelius and Kuhry, 2009; Hugelius et al., 2012).~~ Generally, a higher CN ratio suggests less degraded organic C, while a lower CN ratio points towards already partly degraded C before incorporation into permafrost (Weiss et al., 2016). Even though the CN ratio cannot be taken as a single variable to estimate the recalcitrance
20 of the soil organic matter~~.~~, it provides a first indication of the potential degradability of C stored in permafrost soils (Kuhry and Vitt, 1996; Hugelius and Kuhry, 2009; Hugelius et al., 2012). ~~Schädel et al. (2014) showed that the CN ratio can be an index for the decomposability of C stored in permafrost soils and the potential for C loss upon thaw.~~

        Generally, ice-rich landscapes are underrepresented in pan-Arctic permafrost C pool inventories and the variability of these environments is poorly accounted for. Especially the deep C and N stocks below one meter depth remain associated
25 with high uncertainties due to low sample numbers. In addition, thermokarst areas are temporally dynamic and heterogeneous environments whose characteristics are difficult to generalize and characterize. A wide range of local case studies is needed to capture spatial variability and to improve C pool estimations. This study presents new data on C and N storage in two Yedoma regions in the North of East Siberia and analyzes the variability of C and N contents along landscape gradients extending from Yedoma uplands into adjacent drained ~~thermokarst~~ thaw lake basins (DTLB), investigating whether C and N storage is
30 significantly higher in DTLBs than in Yedoma soils as proposed in regional studies by Strauss et al. (2013), or Walter Anthony et al. (2014).

        In this study, sediment cores up to 3 meter depth from typical thermokarst-affected Yedoma regions were analyzed 1) to quantify the organic C and N variability with depth and along geomorphologic gradients in thermokarst-affected terrain; 2) to understand depositional chronologies as well as C accumulation rates; and 3) in combination with a satellite image based

terrain classification to quantify landscape-scale SOC and N inventories for the study areas Bykovsky Peninsula and Sobo-Sise Island.

2 Material and methods

2.1 Study area

5   The two study areas are situated in the North of East Siberia in the Lena River Delta region (Fig. 1). The first study site, Sobo-Sise Island (72°29' N, 128°16' E), is a Yedoma remnant within the eastern Lena Delta. These remnants are commonly referred to as the third geomorphological river delta terrace (Schwamborn et al., 2002). According to Morgenstern et al. (2011), Sobo-Sise Island accounts for almost 16% of the entire Yedoma coverage in the Lena Delta. It is characterized by Yedoma uplands but also features permafrost degradation landforms such as thermokarst lakes, drained thaw lake basin (DTLB), and thermo-
10 erosional gullies. Sobo-Sise is located between two of the main channels of the Lena Delta (Sardakhskaya and Bykovskaya channels), elongated in east-west direction (45 km) and has an area of 336 km^2. Very few studies have been conducted on the depositional characteristics of Sobo-Sise. For example, Grigoriev (1993) dated a mammoth bone from a Yedoma cliff on Sobo-Sise and Grigoriev (2007) investigated the shore erosion on Sobo-Sise's coastline. Morgenstern et al. (2011) as well as Nitze and Grosse (2016) included Sobo-Sise in regional remote sensing studies aiming at the quantification of thermokarst lakes and
15 basins and surface landscape changes, respectively.

The second study site, Bykovsky Peninsula (71°51' N, 129°19' E), is similar to Sobo-Sise and also dominated by Yedoma uplands that are intersected by thermokarst lakes, drained thermokarst lake basins and thermo-erosional gullies. The Bykovsky Peninsula is located to the southeast of the Lena River Delta at the Laptev Sea coast and represents an erosional remnant of a Late Pleistocene Yedoma accumulation plain blanketing the foreland of low mountain ridges (Grosse et al., 2007).
20 The peninsula is a narrow land tongue with a width between 1 – 4 kilometers and has an area of 167 km^2. In contrast to Sobo-Sise Island in the Lena Delta, the Bykovsky Peninsula is strongly affected by rapid coastal erosion from all sides and by coastal inundation, manifested in several thermokarst lagoons. Studies on the Bykovsky Peninsula focused mostly on paleoenvironmental reconstructions using Late Quaternary deposits at the exposure Mamontovy Khayata (Kunitsky, 1989; Slagoda 1991, 1993; Griogriev, 1993; Siegert et al., 2002; Meyer et al., 2002; Schirrmeister et al., 2002a). Kholodov et al.
25 (2006) described organic matter characteristics in Alas and Yedoma deposits, Griogriev et al. (1996) and Lantuit et al. (2011) determined coastal erosion rates on the coasts of Bykovsky Peninsula, and Grosse et al. (2005) mapped the periglacial geomorphology based on remote sensing data.

The climate of Sobo-Sise Island and Bykovksy Peninsula is continental, despite their proximity to the coast. Both sites are dominated by polar tundra climate (Peel et al., 2007). The mean annual air temperature (MAAT; period 1998-2011)
30 on Samoylov Island (the closest weather station to Sobo-Sise, around 50 km to the west) is -12.5°C with an approximate mean annual precipitation of 180-200 mm (including mean summer rainfall and mean snow water equivalent, period 1998-2011) (Boike et al., 2013). On Bykovsky, the climate is similar with a MAAT of -12.9°C (period 1933-2013) at the closest weather

station in Tiksi (Günther et al., 2015), but a higher mean annual precipitation with around 240-260 mm (Grigoriev, 1993). The higher precipitation can be explained by the influence of the Laptev Sea and the mountain ridge nearby in the hinterland (Boike et al., 2013). In both study sites, permafrost is continuous and is assumed to have a thickness of about 500-650 m (Griogriev, 1993). Boike et al. (2013) reported a mean annual permafrost temperature at Samoylov Island to be -8.6°C in 10.7 m depth.

5   In both study sites, the tundra vegetation is sparse and is limited by the short growing season (June to September). The vegetation composition is dominated by sedges, grasses, mosses, lichen and sporadic dwarf shrubs (*salix* species). According to Schneider et al. (2009) most of Sobo-Sise Island is classified as moist grass- and moss-dominated tundra and wet sedge- and moss-dominated tundra. In the Circum Arctic Vegetation Map (Walker et al., 2005), large parts of the Lena River Delta including Sobo-Sise Island are classified as sedge, moss, dwarf shrub wetland and Bykovksy Peninsula is classified

10   as non-tussock sedge, dwarf-shrub, moss tundra.

      Following the US Soil Taxonomy (Soil Survey Staff, 2014) the soil types in both study sites belong to the Gelisol order with its suborders Turbels and Orthels. Only two soil profiles sampled in thermokarst deposits in this study contain thicker organic layers and can be considered as Histels. Permafrost occurs in almost all sampled sites within the first meter. Active layer thickness ranges from a minimum of 18 cm in thermokarst deposits to a maximum of 84 cm in sandy fluvial

15   deposits with a mean of all sampled sites of 40 cm (median 41 cm). Only in two sites in non-vegetated, sandy, temporally flooded Lena River floodplain deposits of Sobo-Sise, permafrost was not present near the surface and these soils can be classified as Entisols.

2.2 Field work

Soil samples were collected in August 2014 along four transects of 500 m (BYK14-T3) and 600 m (BYK14-T2, SOB14-T1,

20   SOB14-T2) length. We chose transects to cover key geomorphologic gradients of the thermokarst-affected landscapes starting on Yedoma uplands and passing through different stages of Yedoma degradation (including Yedoma slopes) and stages of the thermokarst lake cycle. Similar transect-based approaches were used in other regions of Siberia (Siewert et al., 2015; Palmtag et al., 2015), Canada (Hugelius et al., 2010) and Alaska (Jorgenson, 2000; Kanevskiy et al., 2014). We determined the starting points as well as the direction of each transect. To include randomness, tThe ssampling points along the transects were then

25   chosen at equidistant intervals in alignment with the scale of landscape features at a site (stratified sampling). On the first transect (SOB14-T1) a 150 m and on the second transect (SOB14-T2) a 100 m distance between sampling points was chosen. The first transect on Sobo-Sise extended from a Yedoma upland into the adjacent DTLB. The second transect extended from a Yedoma upland, crossing a DTLB and ending in fluvial deposits of the floodplain. Additional non-random sample points were collected on a- baydzherakhs (erosional remnants of polygon centers forming thermokarst hills) and two DTLBs. No

30   cores were taken from extant thermokarst lakes or thermo-erosional gullies. On Bykovsky Peninsula, transects were chosen with the same approach with a 150 m distance on the first transect (BYK14-T2) and 100 m on the second transect (BYK14-T3) between the sampling points. BYK14-T2 runs from one DTLB over a Yedoma remnant covered with baydzherakhs into

another adjacent DTLB. BYK14-T3 again was similar to the Sobo-Sise transects, running from top of a Yedoma upland into an adjacent DTLB.

Along the transects, soil pits were excavated down to the bottom of the active layer. A soil profile description was made and fixed-volume samples were collected with a metal cylinder of known volume. After sampling the active layer, permafrost cores and samples were collected with a SIPRE (Snow, Ice and Permafrost Research Establishment) auger barrel drill (Jon´s Machine Shop, Fairbanks, USA) with a diameter of 7.62 cm (3"). Total sampling depths ranged from 45 cm to 318 cm. As a result, at 23 sites the whole soil profile was sampled and characterized including active, transient and permafrost layers and at five additional sites only the active layer was sampled. A permafrost core description was made and the cores were subsampled in the field in five to ten centimeter intervals depending on facies horizons. The visual core description included cryostratigraphy according to French and Shur (2010) as well as a description of the lithology and plant macrofossils.

2.3 Laboratory analysis

In total 455 samples were processed for total carbon (TC), total nitrogen (TN) and total organic carbon (TOC). Samples were freeze-dried, homogenized by grinding prior to measurement of 5-8 mg of the samples with a Vario EL III Elemental Analyzer for TC and TN. Both, %C and N were measured in one run. We measured two replicates of each sample where we accept a <5% deviation for the two . Afterwardsmeasurements. The sensitivity of the Elemental Analyzer is < 0.1%. Afterwards, samples were measured for TOC (15-100 mg, depending on the TC content) with a Vario Max C Elemental Analyzer. Again, we allow a deviation of <5% for the double measurements. Total inorganic carbon (TIC) iswas then calculated as the difference between TC and TOC. In addition, the carbon-nitrogen ratio (CN ratio) was calculated as quotient between TOC and TN contents.

Based on Hugelius et al. (2010), the (SOC) storage was calculated for each sample using Eq. (1):

$$\text{SOC [kg/m}^2\text{]} = \text{TOC [\%]} \times \text{BD [g/cm}^3\text{]} \times (1 - \text{CF}) \times \text{length [cm]} \times 10 \tag{1}$$

Here, TOC is the total organic C content derived from the elemental analysis, BD is the dry bulk density of the sample, CF is the coarse fragment fraction (Ø > 2 mm) (which was zero because of the absence of coarse fragments in the sampled soils), and length is the actual sample length. The sample-specific SOC contents were added up to the reference depths of 0 – 30 cm, 0 – 100 cm, 0 – 200 cm. If the cores were not recovered completely, missing core intervals, or respectively missing SOC contents, were interpolated between adjacent samples or from samples with the same characteristics following the field notes. The ice content in a sample is reflected in the dry bulk density and therefore included in the calculations. The SOC contents for the different reference depths however do not include ice wedge volumes. Ice wedge volume was included in a later step when scaling site-specific SOC stocks to the landscape level. Likewise the N storage was calculated for individual samples and for the different reference depths.

In addition, 25 sub-samples from various depths of seven different sampling sites were chosen for radiocarbon dating of organic macro fossils. All samples were wet-sieved with a 2µm sieve and plant macro remains (mostly moss leaves or sedge

stems) were handpicked under a microscope. In a few cases with insufficient macro remains, bulk samples were selected. Samples were then submitted to the Radiocarbon Laboratory in Poznan, Poland, where the samples were analyzed and dated with the accelerated mass spectrometer (AMS) dating method (Goslar et al., 2004). The obtained radiocarbon ages were eventually calibrated with the Calib 7.1 software to calibrated radiocarbon years before present (cal. a BP) (Stuiver and Reimer, 5   1993; Stuiver et al., 2017).

2.4 Landform classification and upscaling C and N pools

All geospatial analyses were performed in the ESRI ArcGIS 10.1 and ENVI 5.3 software. For both Sobo-Sise Island and Bykovsky Peninsula, multispectral RapidEye Images (pixel resolution 5 m) in combination with high resolution digital elevation models (DEM) were used to classify the landscape into the dominant landscape features. For Sobo-Sise Island two 10   scenes from the same date (27th July 2014) were orthorectified and mosaicked together to cover the entire island. To increase the data basis, the RapidEye mosaic from the 27th July 2014 was stacked with another RapidEye Scene (acquisition: 30th June 2014) which covers the entire island. The same scenes (27th July and 30th June 2014 images) were also used for Bykovsky Peninsula, stacked together with an additional scene acquired at 9th Sept. 2014 since the first scene does not cover the entire peninsula. This procedure assures that additional landform variability from the phenological stages of the tundra vegetation at 15   both study sites are captured by at least two RapidEye scenes entirely.

A maximum likelihood supervised classification relying on training areas was used to classify the landscape into the predominant landscape features. Identification of training areas also has been facilitated through near-simultaneous acquisition of RapidEye imagery to our field work. Training areas were chosen based on field notes and field knowledge. For Sobo-Sise Island the different RapidEye images were stacked with a DEM (pixel resolution 2 m) that had been derived from 20   photogrammetric processing of three overlapping GeoEye stereo image pairs (acquisition dates range from 27th July to 15th August 2014). For Bykovsky Peninsula, a DEM was derived from overlapping WorldView-1 and WorldView-2 stereo image pairs (acquisition period: 25th to 29th Aug. 2015) and again combined with the 15 band deep multispectral RapidEye image stack to run the maximum likelihood classification. Adding the DEM allowed enhanced classification of Yedoma uplands, since plant communities on Yedoma uplands cannot be entirely distinguished from those in DTLBs based only on spectral 25   signatures. This advantage was already demonstrated by Grosse et al. (2006) and Siewert et al. (2016) who showed that by including a DEM non-degraded Yedoma uplands and partly degraded Yedoma uplands could be better discriminated compared to image classification only.

The two landform classification for Sobo-Sise and Bykovsky Peninsula initially included the main geomorphological units *Yedoma upland*, *partly degraded Yedoma* (Yedoma slope), and *DTLBs* of different generations. However, due to the 30   small amount of collected sampling sites in DTLBs of different generations, the landform classes of DTLBs were merged to a single class 'Thermokarst' for the upscaling. The final landform classification used for upscaling included the following classes: *Yedoma uplands*, *Degraded Yedoma / Yedoma slope*, *Thermokarst,* and *Lakes*. The areas of lakes were excluded from upscaling since this study focuses on terrestrial soil C storage and no lake cores were collected.

The landform classification accuracy was based on field-based ground truthing points ~~as well as~~complementary with data points extracted from high resolution imagery~~.~~. ~~These were~~The high resolution imagery include~~ from~~ a GeoEye (Sobo-Sise Island), WorldView2 (Bykovsky Peninsula) and aerial photography to assess the correctness of classification and overlap with the sampled field sites.~~ ~~For each study area, 300 randomly selected points and an additional 20 points for each landform class were manually classified and then compared with the landform classification -based on the RapidEye satellite imagery.

The total SOC and N storage for Sobo-Sise and Bykovsky Peninsula was based on mean C stocks of the collected sampling sites for the reference depths 0-30 cm, 0-100 cm, and 0-200 cm of each class. The mean stocks were upscaled based on the areal extent of the corresponding landform class. This approach allows a first estimate of the potential C and N storage in the study areas for the first two meters of soil. ~~For an upscaling of the total study area SOC and N storage, ice wedge content was included in the calculation to not overestimate the C and N stocks.~~ Confidence intervals for the mean SOC and N landscape stocks were calculated according to Hugelius (2012). However, these confidence intervals do not include ~~uncertainties in ice wedge volume estimation or~~ uncertainties evolving from the landform classification based upscaling.

To not overestimate the C and N stocks in the upscaling, we accounted for the ice wedge volume in the landscape carbon and nitrogen calculations.~~ ~~ Ice wedge contents for thermokarst deposits were adopted from the study of Ulrich et al. (2014) as a mean value derived from the maximum ice wedge contents from their three Northeast Siberian study areas Ebe-Basyn-Sise, Cape Mamontov Klyk and Buor Khaya Peninsula. This resulted in a mean ice wedge volume of 9% ± 3% (standard deviation) for thermokarst deposits which is similar to what Kanevskiy et al. (2013) found for drained lake basins in Arctic Alaska with 8%. For the estimation of Yedoma upland ice wedge volume, the GIS based approach from Günther et al. (2015) was applied for Sobo-Sise. We ortho-rectified the GeoEye image using our high resolution DEM, in order to ensure consistent mapping in an image free of geometrical distortions. We mapped more than 1500 baydzerakhs that appeared in clusters on slopes around thermokarst lakes and along thermo-erosional valleys and river banks to determine the spatial dimensions of ice wedge polygons (Voronoi diagram). The largest possible circle within each polygon served as a proxy for the sediment fraction of the polygon and was put in relation to the remaining size of the polygon, representing the ice wedge fraction. This resulted in a mean ice wedge volume of 40% ± 8% (standard deviation). For Yedoma uplands on Bykovsky Peninsula an ice wedge volume of 44% was applied, which is the mean macro ground ice content on nearby Muostakh Island (Günther et al., 2015). Both, Muostakh Island and Bykovsky Peninsula have formerly been connected with each other (Grigoriev, 1993) and are now separated by a 15 km wide sound. For the active layer, we assumed no ice wedge volume for the calculations. Mean active layer depths for the different classes were derived from the collected soil sites. Mean active layer depths for the sampled sites are presented in the supplementary material Table S1.

3 Results

3.1 Sedimentological results

Table 1 presents the laboratory results, indicating that samples from the Bykovsky Peninsula (6.6% ± 7.4) have a higher TOC content than samples from Sobo-Sise Island (3.5% ± 3.8). Differentiating into the various landform types, samples from thermokarst on Sobo-Sise store less TOC (3.6% ± 3.9) than samples from Yedoma uplands (4.3% ± 4.2) which is constrasting with the Bykovsky site (7.9% ± 9.0 for thermokarst and 5.1% ± 4.3 for Yedoma upland). However, the standard deviations and therefore the variance are higher on the Bykovsky Peninsula thermokarst samples.

The total nitrogen (TN) contents show a similar pattern like the TOC values. There is less TN in the samples from Sobo-Sise. There are, however, only very small differences in TN between the different landform types for both study areas. Whereas there is slightly more TN in Yedoma upland samples than thermokarst samples on Sobo-Sise, there is less in Yedoma uplands compared to thermokarst on Bykovsky Peninsula. However, when looking at the median, the sample series (Yedoma upland on Sobo, Yedoma upland on Bykovsky and thermokarst on Bykovsky) tend to be similar (see Table S2 with the median values in the supplementary material).

Volumetric ice contents are very similar for all the sampled cores. For both study sites as well as for Yedoma and thermokarst the mean values range between 61% and 67%. The only exceptions are the samples from fluvial sandy deposits on Sobo-Sise Island with a mean value of 45% (see Table 1). Active layer samples were excluded from this analysis.

CN ratios also show a similar pattern across all classes, with mean CN ratios ranging from 10.7 to 13.2 for the different geomorphological units. However when separating CN ratios into active layer and permafrost layer samples, active layer samples show a higher CN ratio than samples in the permafrost layer at both study sites and in all classes. Mean CN ratios for active layer samples (samples from cores of same landform units combined) are: 15.8; 20.1; 12.5; 17.0 for Sobo-Sise Yedoma uplands, Sobo-Sise Thermokarst, Bykovsky Yedoma Upland and Bykovsky Thermokarst, respectively. For permafrost samples mean CN ratios are: 11.1; 10.3; 10.1; 11.7 for Sobo-Sise Yedoma uplands, Sobo-Sise Thermokarst, Bykovsky Yedoma Upland and Bykovsky Thermokarst, respectively. In all cases, active layer samples have higher CN ratios and there is a moderate correlation of decreasing CN ratio with increasing depth for three classes, and one weak correlation (Bykovsky Thermokarst) of decreasing CN ratio with increasing depth (Fig. 2).

3.2 Sampling site SOC and N stocks

The TOC and bulk density values were used to estimate the site SOC stocks which were averaged for the different landform types (Fig. 3). Mean sampling site SOC stocks (excluding ice wedge volume) were higher for Yedoma upland sites than for thermokarst sites for the reference depths of 0-30 cm and 0-100 cm for both study sites (Fig. 3). SOC storages for 0-100 cm for Sobo-Sise are 25.3 ± 8.0 kg C m^{-2} for Yedoma upland and 19.2 ± 5.9 kg C m^{-2} for thermokarst sites. For fluvial deposits only one profile down to one meter depth was collected with an SOC stock of 11.2 kg C m^{-2}. Also for 0-200 cm more SOC is stored in Yedoma upland soils. The findings for Bykovsky Peninsula are similar with more C stored in Yedoma uplands sites

in the first meter of soil than in thermokarst sites, despite the fact that a higher mean TOC content was found in the thermokarst samples. For 0-100 cm Yedoma upland sites store 29.7 ± 12.9 kg C m^{-2} and thermokarst sites store 23.9 ± 9.7 kg C m^{-2}. For 0-200 cm there is more organic C stored in thermokarst than in Yedoma upland soils. However, this estimation is only based on one relatively C rich core (BYK14-T3-3)., since this is the only core reaching a depth of two meters for thermokarst on Bykovsky Peninsula. Therefore the carbon estimation for thermokarst on Bykovsky Peninsula for the soil interval 0-200 cm has to be interpreted carefully.

The mean sampling site soil N stock (excluding ice wedge volume) for Yedoma upland sites on Sobo-Sise Island is 2.3 ± 1.1 kg N m^{-2} (0-100 cm) and for thermokarst sites 1.4 ± 0.4 kg N m^{-2} (Fig. 4). Mean profile N storage for the first meter of soil on Bykovsky Peninsula are 2.6 kg N m^{-2} ± 0.9 for Yedoma upland sites and 1.9 kg N m^{-2} ± 0.6 for thermokarst sites.

3.3 Upscaling: Landscape SOC and N stocks

The landform classification (Fig 5.) shows that 43% and 51% of the landscape on Sobo-Sise and Bykovsky, respectively, are Yedoma or partly degraded Yedoma. Thermokarst depressions cover approximately 43% on Sobo-Sise and 38% on Bykovsky (excluding lakes and lagoons which cover 14% and 11% of the landscapes, respectively).

Based on the landform classification and the sampling site C contents the total C storage for the two study regions was calculated. In total, 5.81 Tg of organic C are stored in the first meter of soil on Sobo-Sise (288 km^2) of which around 57% are stored within the active layer. These calculations include a landscape-wide ice wedge volume of 40% for Yedoma and 9% for thermokarst, always applied for deposits below the active layer. This results in an average SOC storage for non-lake areas on Sobo-Sise of 20.2 ± 2.9 (95% confidence interval) kg C m^{-2} for 0-100 cm. For Bykovsky Peninsula (154 km^2) the results are similar. In the first meter of soil, 3.98 Tg of organic C are stored of which 58% are stored in the active layer, including an ice wedge volume of 44% for Yedoma and 9% for thermokarst. This results in a landscape average of 25.9 ± 9.3 kg C m^{-2} (excluding lakes) for 0-100 cm.

Beside the organic C, there is a considerable amount of N stored in the soils of Sobo-Sise Island and Bykovsky Peninsula. About 0.53 Tg of N is stored on Sobo-Sise resulting in a mean N storage of 1.8 ± 0.2 kg N m^{-2} (0-100 cm, excluding lakes). On Bykovsky, a total of 0.34 Tg of N are stored in the first meter of soil. This results in a mean N stock of 2.2 ± 0.5 kg N m^{-2} for 0-100 cm. Mean N and organic C storage for the reference depths and the two study areas are summarized in Table 2 and the total landscape stocks are presented in the supplement Table S3.

3.4 Radiocarbon dates

In general, the radiocarbon dates (Table 3) indicate that organic matter in the first two meters (and in one thermokarst site down to three meters) in both study areas predominantly is of Holocene age. Only one Yedoma upland site (BYK14-T3-6B) has clearly late Pleistocene ages around one meter depth. The two other dated Yedoma upland sites BYK14-T2-3 and SOB14-T2-2 indicate the presence of a thick Holocene cover layer exceeding 1.67 m and 2.23 m, respectively. In general, only one age-depth inversion was found (SOB14-T2-5), at all other sites, organic matter age increased with depth.

In addition, cumulative SOC storage and radiocarbon dates were combined to calculate organic C accumulation rates (Table 4). Figure 6 shows the radiocarbon ages plotted against the cumulative SOC for each sampling site, indicating the C accumulation rates. The plots show that the C accumulation rate was fairly linear in all of the cores, especially when removing one age-inversion from a core (SOB14-T2-5 with 5,517 cal yr BP) and one outlier (the exceptional old date from BYK14-T2-3 with 45,203 cal yr BP), however the accumulation rates vary for both the two classes thermokarst and Yedoma upland soils as well as for single sampling sites. The highest mean SOC accumulation rate is found in the thermokarst site SOB14-T2-5 with 49.7 g C m^{-2} yr^{-1} (and 300 cm of sediment accumulation) which is almost 20 times higher than SOB14-T1-5, another thermokarst site from Sobo-Sise which has a mean organic C accumulation rate of 2.7 g C m^{-2} yr^{-1} (and 200 cm of sediment accumulation). This is also reflected in the different sediment accumulation rates (Table 4). This high variability in sediment and C accumulation rates reveals that even within a small area (the sites are located within 3 km) a high heterogeneity exists in soil forming and C accumulation processes.

4 Discussion

4.1 Site specific soil organic C and N stock characteristics

We found that particularly DTLBs contain less C than what has been estimated by other studies (Strauss et al., 2013; Walter Anthony et al., 2014). However, Strauss et al. (2013) and Walter Anthony et al. (2014) included also samples from greater soil depths and partially included sites from boreal regions with higher net primary productivity, whereas our study was focusing on the first three meters of the soils in a high latitude tundra region. Strauss et al. (2013) did a C inventory for the entire Yedoma region resulting in a SOC storage of 10 + 17/-6 kg m^{-3} for Yedoma and 31 + 23/-18 m^{-3} for thermokarst deposits.

Especially thermokarst sites on Sobo-Sise Island are more depleted in SOC and store less N than the Yedoma upland sites. In contrast to several previous studies investigating drained thermokarst lake basin peat accumulation in Alaska, (Bockheim et al., 2004 Hinkel et al., 2003; Jones et al., 2012) and the Kolyma region in Siberia (Walter Anthony et al 2014), it is clear that the investigated DTLB soils in Sobo-Sise and Bykovsky do not show signs of increased peat formation and contain only thin organic layers. Organic layer depths of the studied DTLBs on Sobo-Sise and Bykovsky Peninsula are largely less than 10 cm with only two sites having thicker organic-rich peaty layers in the top. This indicates that the conditions for peat accumulation in these DTLB were not favorable. Also for Yedoma upland soils, organic layers are relatively shallow (< 10 cm). This is especially important when considering that the organic layer which insulates the ice rich Yedoma deposits from warming and thawing is only thin, rendering the Yedoma in this region vulnerable to active layer deepening and permafrost degradation. Due to the lack of thick organic or peaty layers, most of the profiles were classified as the mineral-dominated Orthels or Turbels. This is consistent with the argumentation in Hugelius et al. (2016) which emphasized that DTLBs do not always contain peaty C rich deposits (Histels).

A key reason for the rather low SOC contents in DTLBs is the low primary productivity of the study sites at ~72° N latitude. In addition, the sampled DTLB represent only a fraction of all the basins in the study areas and may not be

representative of the full range of basin ages. Previous studies from Alaska indicated that older basins contained thicker organic layers than younger basin (Hinkel et al. 2003; Jones et al., 2012). Other reasons may include the topographic gradient that impacts how well the DTLB are drained and whether these basins remain waterlogged peat-forming landscapes or become dry environments not favorable for peat formation. Several of the studied DTLB were eroded by the Lena River (Sobo-Sise) or
5   the sea (Bykovsky Peninsula) and some have deeply incised drainage channels, all of which caused rather strong drainage gradients and enhanced landscape drying.

Our mean landscape SOC stocks for Sobo-Sise Island and Bykovsky Peninsula are, however, in the same range of previous studies in similar settings. E.g. Siewert et al. (2016) found a mean of 19.2 kg C m^{-2} (0-100 cm) in another Yedoma dominated landscape in the central Lena River Delta. Zubrzycki et al. (2013) investigated the SOC characteristics of the
10 Holocene river terrace and the active floodplain in the Lena River Delta and found mean SOC stocks of 29.5 kg C m^{-2} and 13.6 kg C m^{-2}, respectively. The C storage of the active floodplain is therefore very similar to the 11.2 kg C m^{-2} for fluvial deposits in our study area. Ping et al. (2011) also investigated C storage along the Alaska Beaufort Sea coastline and found a normalized mean landscape storage of 38 kg C m^{-2}. However, this number is based on profiles only and not on a landscape based upscaling. Shmelev et al. (2017) investigated sites in the Kolyma Yedoma region and found a C storage of 17.0 ± 51.1
15 kg C m^{-3} (note that it is kg C m^{-3}) for the Holocene cover layer, 16.2 ± 31.3 kg C m^{-3} for the Alas (thermokarst) deposits and 14.0 ± 23.5 kg C m^{-3} for Yedoma deposits. These values however refer not only to the first two meters of soil covering Pleistocene Ice Complex deposits but to the upper 25 m of Yedoma Ice Complex. Also, Webb et al. (2017) investigated deep (15 m) C stocks in a larch dominated Yedoma area in the Kolyma river basin and found more organic C in the Alas site than in the Yedoma site. Based on a landscape upscaling, Siewert et al. (2015) calculated the SOC storage for the Kytalik region, a
20 Yedoma and thermokarst dominated tundra in the Yana-Indigirka Lowland, to 25.8 ± 9.9 kg C m^{-2} for the first meter of soils which falls in the range spanned by the Sobo-Sise Island and Bykovsky Peninsula calculations.

Aside from organic C, a significant amount of N is stored in the soils of Bykovsky Peninsula and Sobo-Sise Island, almost twice as much as what has been found by the study from Zubrzycki et al. (2013) for the Holocene river terrace (1.2 kg m^{-2}) and the active floodplain (0.9 kg m^{-2}) of the Lena Delta. Obu et al. (2015) reported higher N storages from the western
25 Canadian Arctic, where 3.4 kg N m^{-2} are stored in cryoturbated or recent disturbed type soils or sediments and Michaelson et al. (2013) calculated a mean N storage of 2.7 kg m^{-2} for Arctic Alaska pedons. The normalized average N storage from the Alaskan Beaufort Sea coast is in the same range with 1.9 kg N m^{-2} (Ping et al., 2011) and also N storages from two study sites on Taymir Peninsula are in the same range, with 1.0 and 1.3 kg N m^{-2} (Palmtag et al., 2016).

Even though the N storages are an order of magnitude lower than the organic C storages, a large amount of N is
30 present in these soils. Since N is the limiting factor for plant growth in Arctic environments (Shaver et al., 1986; Chapin et al., 1995; Mack et al., 2004; Beermann et al., 2015), permafrost thawing will affect the N stocks in the soils. The N could partially become available to plants upon permafrost thawing. However, the role of N and whether it can offset an increased organic carbon release by increased plant growth needs further exploration. In a recent study, Keuper et al. (2017) found that plant available N from thawing permafrost is an additional source for deep-rooting subarctic plants and can increase their biomass

production. Also Salmon et al. (2016) reported that increased that N from thawed permafrost enhances plant growth and biomass, however that it might not offset C from deep deposits. An increase in N has, however, the potential to change the plant productivity and the species composition (Keuper et al., 2012). Keuper et al. (2012) shows that not only dissolved plant available N becomes available with permafrost thawing but also organically bound N can be mineralized at faster rates in thawed near permafrost soils.

However, an increased N availability might stimulate both, vegetation growth but also increase microbial activity (Nowinski et al. 2008). Koven et al. (2015) reports that near surface N released from thawing permafrost might reduce nutrient limitations, even though the same study shows limited importance of the deep soil N to offset deep C release. In an expert assessment and Abbott et al. (2016) stated that even an increase in Arctic and boreal biomass might not offset permafrost carbon release. However, since Since we focused only only focused on total N N stocks, we cannot derive conclusions on potential plant available N in the soils of Sobo-Sise Island and Bykovsky Peninsula and its effect on the primary production or C release. Nevertheless, this first estimation of total N in the soils of Sobo-Sise Island and Bykovsky Peninsula will be relevant for future climate models.

4.2 Upscaling of C and N pools

The total C stocks of our study sites are in the range of other permafrost C studies and confirm previous high C stock estimates from northern permafrost regions (e.g. Hugelius et al., 2014). The landform classification proved to be adequate for the upscaling. The overall accuracy for the classification is 71.5% and 71.1% for Sobo-Sise and Bykovsky, respectively. Additional field data in more different sub-classes and a more diversified classification would further increase the precision of the upscaling. Nevertheless, by including a high resolution DEM, classifying remotely sensed images into geomorphological landform types results in an accurate map for a first estimation of SOC and N stocks on the landscape level. In this context, of particular note is the areal fraction of Yedoma uplands we found on Sobo-Sise Island and the Bykovsky Peninsula of 43% and 51%, respectively. While this is within the range Morgenstern et al. (2011) described for the 3rd terrace of the Lena Delta, on a larger regional level Yedoma coverage is generally lower. For example Veremeeva and Glushkova (2016) calculated 16% of Yedoma coverage for the entire Kolyma Lowland. However, our, higher values are a combination of Yedoma uplands and partly degraded Yedoma slopes. Excluding areas with slopes, 19% of Sobo-Sise and 22% of Bykovsky Peninsula are covered by intact Yedoma uplands not yet significantly affected by thermokarst or erosion.

For upscaling deep C and N pools, the determination of ice wedge volumes is important. In our study we assessed ice wedge volume by a combination of literature values and own values derived form a GIS based analysis of high resolution satellite data. This analysis was based on more than 1500 mapped baydzheraks and resulted in a mean ice wedge volume of 40% for Sobo-Sise Island with a standard deviation of ± 8%. Conducting additional calculations with an ± 8% ice wedge volume for Yedoma uplands and ± 3% for thermokarst areas would lead to a ± 4% higher respective lower landscape SOC stock (± 5% for N) for 0-100 cm and ± 7% of SOC and total N for 0-200 cm for Sobo-Sise Island. While these results are still in the same range, this analysis reveals the importance to assess ice wedge volumes correctly within a landscape for

SOC and N upscaling, especially for deep deposit calculations. For a more detailed upscaling and to capture the entire variability of these heterogeneous environments, additional and deeper soil cores are needed as well as a more detailed estimation of the landscape ice wedge contents will further improve SOC and soil N pool estimations.

4.3 Sediment and organic C accumulation rates

5   Most of the analyzed soil C was of Holocene age. Even for Yedoma upland soils radiocarbon dates indicated a large number of Holocene ages. Hence, the Yedoma uplands appear to be blanketed by Holocene cover material sometimes exceeding a thickness of two meters, which needs to be accounted for in carbon pool inventories, because these two meter cover deposits cannot be considered as Yedoma. In DTLBs, the Holocene age of soil C fits well with the findings from previous studies suggesting that the accumulation of lacustrine sediments, drainage of thermokarst lakes, and accumulation of soils and

10 organic layers in the basins has been occurring mostly during the Holocene (Kaplina 2009; Grosse et al., 2013; Walter Anthony et al., 2014). Based on the radiocarbon dates and the cumulative SOC storages, the accumulation rates for the soil cores were calculated. The mean (linear) C accumulation rate of SOB14-T2-5 with 49.7 g C m^{-2} yr^{-1} is very high, even higher than what has been found by Jones et al. (2012) for paleo peat accumulation rates (9 – 35.2 g C m^{-2} yr^{-1}) in thermokarst basins on the Seward Peninsula. Nevertheless, it has to be considered that this site location is close to the Lena River with only approximately

15 5 m above river water level. Likely, this location is affected by spring flood events which can deposit large amounts of sediments. On the other side, the site SOB14-T1-5 with 2.7 g C m^{-2} yr^{-1} has very low accumulation rates and is most certainly not affected by the Lena River flood. For comparison, Kurganova et al. (2014) find that modern C accumulation on arable land in Russia was on average 9.6 g C m^{-2} yr^{-1} over a 20 year period after abandonment, Hicks Pries et al. (2012) found a mean Holocene C accumulation rate of 25.8 g C m^{-2} yr^{-1} for surface soils and 2.3 g C m^{-2} yr^{-1} for deep soils in subarctic tundra in

20 central Alaska, and Bockheim et al. (2004) found a mean long-term accumulation rate of 13 g C m^{-2} yr^{-1} for the last 5,500 years in DTLBs in Arctic Alaska, however referring to the organic layer only.

       Sediment accumulation rates are all in the same order of magnitude, excluding SOB14-T2-5, which might be affected by the Lena River, with mean accumulation rates for the different thermokarst cores ranging between 0.13 mm yr^{-1} and 0.26 mm yr^{-1} and mean accumulation rates for Yedoma upland cores between 0.10 mm yr^{-1} and 0.57 mm yr^{-1} (Table 4). For

25 comparison, Murton et al. (2015) found sediment accumulation rates between 0.75 and 2.00 mm yr^{-1} for Yedoma silt at Duvanny Yar in the Kolyma Lowland. However, these rates refer to a time period between 38,700 and 23,600 years BP. Also Schirrmeister et al. (2002a, 2002b) found a similar accumulation rate for a Yedoma deposit (Mamontovy Khayata) on Bykovsky Peninsula of about 0.75 mm yr^{-1} for the time period between 60,000 to 6,000 years BP. These rates are slightly higher than the rates calculated in our study. In addition, all presented sediment accumulation rates (Table 4) will be lower

30 when taking into account the ice content within the deposits. Sediment accumulation rates corrected for soil core ice content are presented in the Supplement Table S6.

4.4 Characterizing soil organic carbon

~~The CN ratio provides a first indication of the potential degradability of C stored in permafrost soils (Kuhry and Vitt, 1996; Hugelius and Kuhry, 2009; Hugelius et al., 2012). Generally, a higher CN ratio suggests less degraded organic C, while a lower CN ratio points towards already partly degraded C before incorporation into permafrost (Weiss et al., 2016). Even though the CN ratio cannot be taken as a single variable to estimate the recalcitrance of the soil organic matter, Schädel et al. (2014) showed that the CN ratio can be an index for the decomposability of C stored in permafrost soils and the potential for C loss upon thaw.~~ The rather low CN ratio in our study is common to all sampled soils. Only individual samples showed higher CN ratios and in general there is a trend of decreasing CN ratios with increasing soil depth. Even though the permafrost organic matter is already partly degraded, these finding suggests that organic matter in the top permafrost layer may be remobilized and decomposed when thawed out as the result of fluctuation of the permafrost table due to climate change. Also Strauss et al. (2015) found relatively small CN ratios for Yedoma and thermokarst samples too (median values below 8 and 10), although they looked at samples from deeper deposits. The mean values from our study might be lower too when incorporating samples from greater depths, this is indicated by the decreasing CN ratio with increasing depth. Higher CN values in the upper meter of soil were found by Zubrzycki et al. (2013) with mean values between 20 and 42 from Holocene river terrace and mean values between 13 and 21 for the active floodplain level of the Lena Delta. This indicates fresher material in these deposits compared to Yedoma uplands and DTLB deposits.

4.5 The fate of organic carbon in thermokarst affected Yedoma in Siberia

Permafrost soil layers beneath the active layer and below one meter depth are important for future C remobilization, because models suggest permafrost degradation and thaw well beyond 1 m depth by end of the 21st century (Lawrence et al., 2012; Koven et al., 2013). The cores and the high sample resolution in this study provide detailed information on the C stored in the soil beneath the active layer in the study areas which will be thawed first by future warming. This study provides additional soil C and N data for multiple cores deeper than 100 cm for thermokarst-affected Yedoma landscapes. Studies with such deeper cores are rare and even the NCSCD contains three times more profiles for the 0-100 cm (1778 profiles) interval than for estimations exceeding 100 cm depth (Hugelius et al., 2014).

Our upscaling suggests that the study sites contain significantly more C than soils in temperate climate zones (e.g. Wiesmeier et al., 2012). Both study areas could become sources of organic C and N if permafrost thaw continues in a warming Arctic. An estimation based on the sampled cores and the landform classification shows that with an overall deepening of the active layer of 10 cm 700,000 t C (1.6 kg C m^{-2}) will thaw out in both study areas combined (Table 5). A regional study of Siberian permafrost dynamics (Sazonova et al., 2004) includes scenarios where the active layer deepens by more than 100 cm in Northeastern Siberia at the end of the 21st century. This would result in an additional pool of available SOC of 5,830,000 t (13.2 kg C m^{-2}) in the two study areas combined. In addition, other forms of permafrost thaw than active layer deepening

would further increase the amounts of SOC thawed and mobilized. For example, lake shore erosion rapidly degrades permafrost around lakes and releases organic C to the aquatic environment. Shore erosion not only affects the active layer soils from the top but does affect deeper permafrost soil layers (Walter Anthony et al., 2016). This vulnerability of large currently frozen C pools to thaw highlights the importance of deep permafrost organic C to be considered in future C cycle models.

5 **5 Conclusions**

This study presents the first SOC and N inventories for Sobo-Sise Island and Bykovsky Peninsula, two Yedoma-dominated and thermokarst-affected landscapes in the North of East Siberia for the first two meters of soil. These ice rich permafrost landscapes are vulnerable to climate warming and have the potential to release large amounts of SOC and total N through active layer deepening and permafrost thaw.

10   Sampling sites in DTLBs were found to contain less organic C than soils on the Yedoma upland. Permafrost soils in DTLBs were all of Holocene age and soils of the upper two meters on the Yedoma uplands largely were all part of a Holocene cover layer above late Pleistocene Yedoma deposits. The mean upscaled landscape SOC storage for 0-100 cm is 20.2 ± 2.9 kg C m^{-2} for Sobo-Sise and 25.9 ± 9.3 kg C m^{-2} for Bykovsky Peninsula which results in a total storage of 9.8 Tg C across both study areas for the first meter of soil. Based on our high sample density, detailed C estimations for active layer deepening were

15 derived, suggesting that 5.8 Tg (13.2 kg C m^{-2}) of SOC may become available for microbial degradation due to thaw if the active layer deepens by 100 cm in the two study areas. The N stocks are one order of magnitude lower but nevertheless a mean of 1.8 ± 0.2 kg N m^{-2} are stored on Sobo-Sise and 2.2 ± 0.5 kg N m^{-2} on Bykovsky Peninsula for the 0-100 cm depth interval. Therefore, as a consequence of permafrost thaw not only SOC but also additional N may become available for plants and microorganisms.

20   This study confirms the importance of Yedoma and thermokarst landscapes for the permafrost C pool and adds important shallow and deep C and N data to the permafrost region soil databases. It also shows the high variability of SOC and N distribution in thermokarst-affected Yedoma environments. Our study particularly underlines the benefits of soil cores beyond 1 m depth to capture the high variability both within the soil and the entire landscape. Our result of C and N storage and availability to permafrost thaw in the upper subsurface points towards the fact that not only the amount but also the

25 potential for remobilization and the fate of freshly thawed matter requires more attention in the Yedoma region. Even though Sobo-Sise Island and the Bykovsky Peninsula do not contain extraordinary high SOC stocks in the near-surface permafrost at profile level, they nevertheless have a large potential for rapid mobilization of significant amounts of C due to their large proportion of thaw-vulnerable juvenile Yedoma and thermokarst-affected landscape units.

Author contributions

M.F designed the study; M.F., G.G., J.S., F.G., M.G., G.M.M conducted the field work during the expedition Lena 2014; M.F. carried out the laboratory analysis; F.G. generated the high resolution DEMs; M.F wrote the publication with input from all
5 co-authors.

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Formatiert: Englisch (Vereinigtes Königreich)

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Tables

Table 1: Laboratory results of soil C, N, and ground ice characteristics for the different geomorphological landform units on Sobo-Sise Island and Bykovsky Peninsula. All values are mean values ± standard deviation. Median values for all parameters are provided in the supplement material in Table S2.

	TOC [%]	TIC [%]	TN [%]	C/N [-]	Vol. ice content[a] [%]	SOC [kg/m³]	N [kg/m³]	n
Sobo-Sise	3.5 ± 3.8	0.2 ± 0.4	0.3 ± 0.1	10.9 ± 6.3	61.8 ± 14.8	19.5 ± 12.6	1.7 ± 0.9	279
Sobo-Sise Yedoma upland	4.3 ± 4.2	0.3 ± 0.4	0.3 ± 0.1	12.2 ± 6.8	61.5 ± 15.0	25.7 ± 16.1	2.2 ± 1.1	85
Sobo-Sise Yedoma slope	3.1 ± 1.8	0.1 ± 0.1	0.3 ± 0.1	10.7 ± 2.9	61.6 ± 16.8	19.6 ± 10.0	1.8 ± 0.7	33
Sobo-Sise Thermokarst	3.6 ± 3.9	0.1 ± 0.4	0.3 ± 0.1	11.7 ± 5.7	63.1 ± 13.7	17.6 ± 9.4	1.6 ± 0.6	135
Sobo-Sise Fluvial Deposits	0.8 ± 0.7	0.0 ± 0.1	0.1 ± 0.0	10.8 ± 6.0	45.0 ± 9.4	10.0 ± 7.2	0.9 ± 0.5	26
Bykovsky	6.6 ± 7.4	0.7 ± 0.4	0.5 ± 0.3	11.9 ± 6.5	62.8 ± 16.4	28.9 ± 21.2	2.4 ± 1.2	176
Bykovsky Yedoma upland	5.1 ± 4.3	0.6 ± 0.4	0.4 ± 0.2	10.8 ± 3.5	62.1 ± 13.6	28.1 ± 18.4	2.5 ± 1.2	80
Bykovsky Thermokarst	7.9 ± 9.0	0.8 ± 1.0	0.5 ± 0.4	13.2 ± 7.8	66.4 ± 14.3	29.5 ± 23.3	2.2 ± 1.3	96

5 [a] Intrasedimentary ice (excluding wedge ice volume)

6 **Table 2:** Mean landscape organic C and N storages in kg C m^{-2} ± 95% confidence interval

Study site	SOC Aactive Llayer	SOC 0-30 cm	SOC 0-100 cm	SOC 0-200 cm	N Aactive Llayer	N 0-30 cm	N 0-100 cm	N 0-200 cm
Sobo-Sise Island	11.6 ± 1.94	9.0 ± 1.23	20.2 ± 2.91	31.3 ± 3.56	1.0 ± 0.23	0.7 ± 0.09	1.8 ± 0.16	3.0 ± 0.23
Bykovsky Peninsula	15.0 ± 3.10	10.8 ± 2.25	25.9 ± 9.33	48.4 ± 9.97	1.3 ± 0.21	0.9 ± 0.13	2.2 ± 0.45	4.0 ± 0.37

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Table 3: Radiocarbon dates for selected soil cores

Sample ID	Depth [cm]	Lab. no.	AMS ^{14}C age [yrs BP]	Calib age [yrs BP][a]	Dated material	Weight [mg]	Coordinates Latitude [°]	Longitude [°]
Yedoma upland								
SOB14-T1-1-3	20-24	Poz-74518	970 ± 30	842 ± 46	Sedge stems	13	72.50442	128.03915
DTLB								
SOB14-T1-5-2	10-11	Poz-74451	112.88 ± 0.32 pMC	modern	Moss leaves/stems	12	72.50964	128.03435
SOB14-T1-5-15	148-150	Poz-74452	4460 ± 35	5058 ± 91	Bulk organic	12	72.50964	128.03435
SOB14-T1-5-19	187-200	Poz-74454	6605 ± 30	7481 ± 44	Moss leaves/stems	10	72.50964	128.03435
Yedoma upland								
SOB14-T2-2-7	55-65	Poz-74455	1420 ± 30	1329 ± 39	Bark of a twig	12	72.52853	127.97281
SOB14-T2-2-16	119-122	Poz-74519	3065 ± 35	3272 ± 92	Sedge stems	17	72.52853	127.97281
SOB14-T2-2-24	173-179	Poz-74538	6200 ± 50	7114 ± 137	Wood with bark	22	72.52853	127.97281
SOB14-T2-2-30	218-223	Poz-74522	8800 ± 50	9807 ± 154	Bulk organic	20	72.52853	127.97281
DTLB								
SOB14-T2-5-2	5-6	Poz-74523	111.54 ± 0.33 pMC	modern	Moss leaves/stems	28	72.52852	127.98176
SOB14-T2-5-10	67-74	Poz-74524	135 ± 30	168 ± 110	Bulk organic	25	72.52852	127.98176
SOB14-T2-5-19	145-156	Poz-74525	350 ± 30	364 ± 49	Sedge stems	13	72.52852	127.98176
SOB14-T2-5-31	273-278	Poz-74526	4735 ± 40	5517 ± 70	Bulk organic	20	72.52852	127.98176
SOB14-T2-5-34	299-303	Poz-74857	970 ± 30	842 ± 46	Deciduous leaves	13	72.52852	127.98176
Baydzerakh								
BYK14-T2-3-2b	14-16	Poz-74732	595 ± 30	615 ± 37	Sedge stems/leaves	15	71.86050	129.29276
BYK14-T2-3-4	40-45	Poz-74733	1155 ± 30	1109 ± 67	Sedge stems	21	71.86050	129.29276
BYK14-T2-3-8	68-75	Poz-74734	1670 ± 30	1576 ± 53	Sedge stems	40	71.86050	129.29276
BYK14-T2-3-19	159-167	Poz-74735	2715 ± 30	2812 ± 52	Sedge stems	31	71.86050	129.29276
BYK14-T2-3-20	178-179	Poz-74737	41600 ± 1400	45203 ± 2512	Large wood piece	118	71.86050	129.29276
DTLB								
BYK14-T2-4-4	23-24	Poz-74738	600 ± 30	615 ± 38	Sedge stems	15	71.86143	129.29530
BYK14-T2-4-10	45-48	Poz-74739	1250 ± 30	1222 ± 51	Sedge stems	16	71.86143	129.29530
BYK14-T2-4-16	76-79	Poz-74740	1545 ± 30	1449 ± 78	Sedge stems	22	71.86143	129.29530
BYK14-T2-4-22	117-125	Poz-74741	8350 ± 50	9368 ± 119	Plant remains	60	71.86143	129.29530
Yedoma upland								
BYK14-T3-6B-14	110-116	Poz-89712	12990 ± 70	15533 ± 256	Sedge stems	20	71.82236	129.31537
BYK14-T3-6B-18	142-148	Poz-89713	13350 ± 70	16048 ± 225	Bulk organic	16	71.82236	129.31537
BYK14-T3-6B-23	185-191	Poz-89714	14770 ± 70	17970 ± 215	Bulk organic	20	71.82236	129.31537

[a]calibrated with Calib 7.1 software (Stuiver et al., 2017)

Table 4: Sediment (sedim. rate) and organic carbon accumulation rates (OC acc. rate). Sediment accumulation rates areis based on the depth of the sample and the calibrated radiocarbon date. Organic carbon accumulation rates areis based on cumulative soil organic carbon (Cum SOC) storage at a specific depth and the calibrated radiocarbon date at the corresponding depth. Mean sediment and organic carbon accumulation rates are calculated always referring to the soil surface (depth = 0 cm and Cum SOC = 0 kg C m^{-2}). Relative sediment and organic carbon accumulation rates are calculated always referring to the sample above a particular sample.

Sample	Age[a] [cal yr BP]	Cum SOC [kg C m^{-2}]	Depth [cm]	Mean sedim. rate [mm yr^{-1}]	Relative sedim. rate [mm yr^{-1}]	Mean OC acc. rate [g C m^{-2} yr^{-1}]	Relative OC acc. rate [g C m^{-2} yr^{-1}]
SOB14-T1-1-3	842	10.29	19.5-23.5	0.26	0.26	12.2	12.2
SOB14-T1-5-2	modern	1.21	10-11	na	na	na	na
SOB14-T1-5-15	5058	13.13	148-150	0.29	0.29	2.6	2.6
SOB14-T1-5-19	7481	20.34	187-200	0.26	0.18	2.7	3.0
SOB14-T2-2-7	1329	18.30	55-65	0.45	0.45	13.8	13.8
SOB14-T2-2-16	3272	32.47	119-122	0.37	0.31	9.9	7.3
SOB14-T2-2-24	7113.5	43.13	173-179	0.25	0.14	6.1	2.8
SOB14-T2-2-30	9807	50.31	218-223	0.22	0.17	5.1	2.7
SOB14-T2-5-2	modern	0.54	5-6	na	na	na	na
SOB14-T2-5-10	168	12.43	67-74	4.20	4.20	74.0	74.0
SOB14-T2-5-19	364	23.97	145-156	4.13	4.08	65.9	58.9
SOB14-T2-5-31	5517	38.78	273-278	0.50	0.24	7.0	2.9
SOB14-T2-5-34	842	41.83	298.5-302.5	3.57	3.14	49.7	37.4
BYK14-T2-3-2b	615	10.76	14-16	0.24	0.24	17.5	17.5
BYK14-T2-3-4	1109	26.07	40-45	0.38	0.56	23.5	31.0
BYK14-T2-3-8	1576	43.14	68-75	0.45	0.62	27.4	36.6
BYK14-T2-3-19	2812	66.24	159-167	0.58	0.74	23.6	18.7
BYK14-T2-3-20	45203	71.34	178-179	0.04	0.004	1.6	0.1
BYK14-T2-4-4	615	10.87	23-24	0.38	0.38	17.7	17.7
BYK14-T2-4-10	1222	17.63	45-48	0.38	0.38	14.4	11.1
BYK14-T2-4-16	1449	29.10	76-79	0.53	1.37	20.1	50.5
BYK14-T2-4-22	9368	34.23	117-125	0.13	0.05	3.7	0.6
BYK14-T3-6B-14	15533	34.69	110-116	0.07	0.07	2.2	2.2
BYK14-T3-6B-18	16048	38.96	142-148	0.09	0.62	2.4	8.3
BYK14-T3-6B-23	17970	42.89	185-191	0.10	0.22	2.4	2.0

[a]radiocarbon dates were calibrated with the Calib 7.1 software (Stuiver et al., 2017)

Table 5: Potential C thaw out for different active layer deepening scenarios
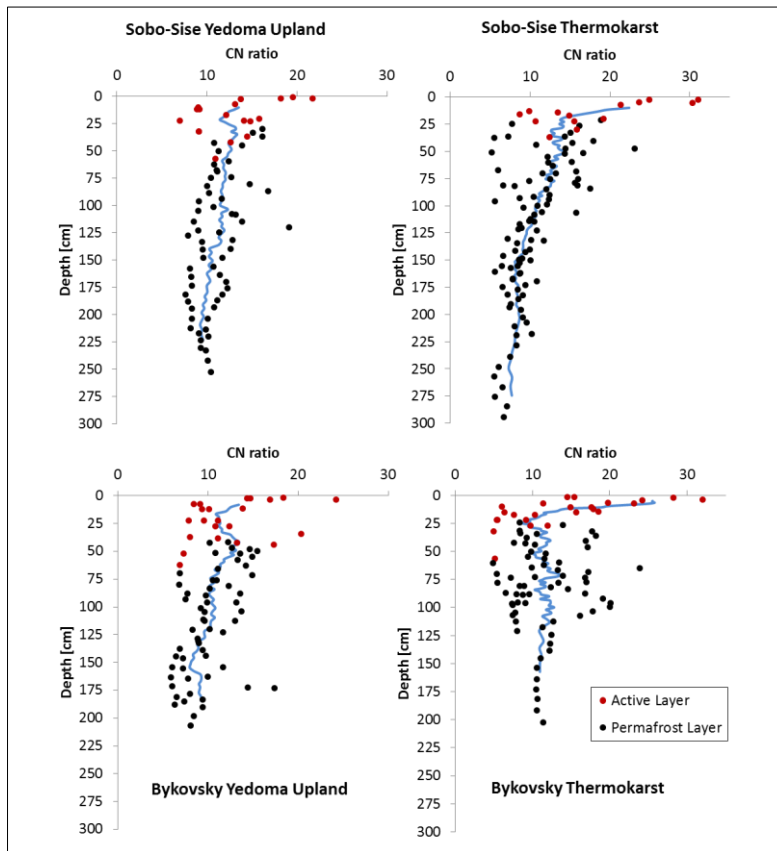
	Active Layer + 10 cm	Active Layer + 20 cm	Active Layer + 50 cm	Active Layer + 100 cm	Area
Sobo-Sise Island	0.45 Tg	0.80 Tg	1.62 Tg	3.40 Tg	287.7 km^2
Bykovsky Peninsula	0.25 Tg	0.48 Tg	1.32 Tg	2.44 Tg	154.0 km^2
Total	0.70 Tg	1.28 Tg	2.94 Tg	5.83 Tg	441.7 km^2

Figures
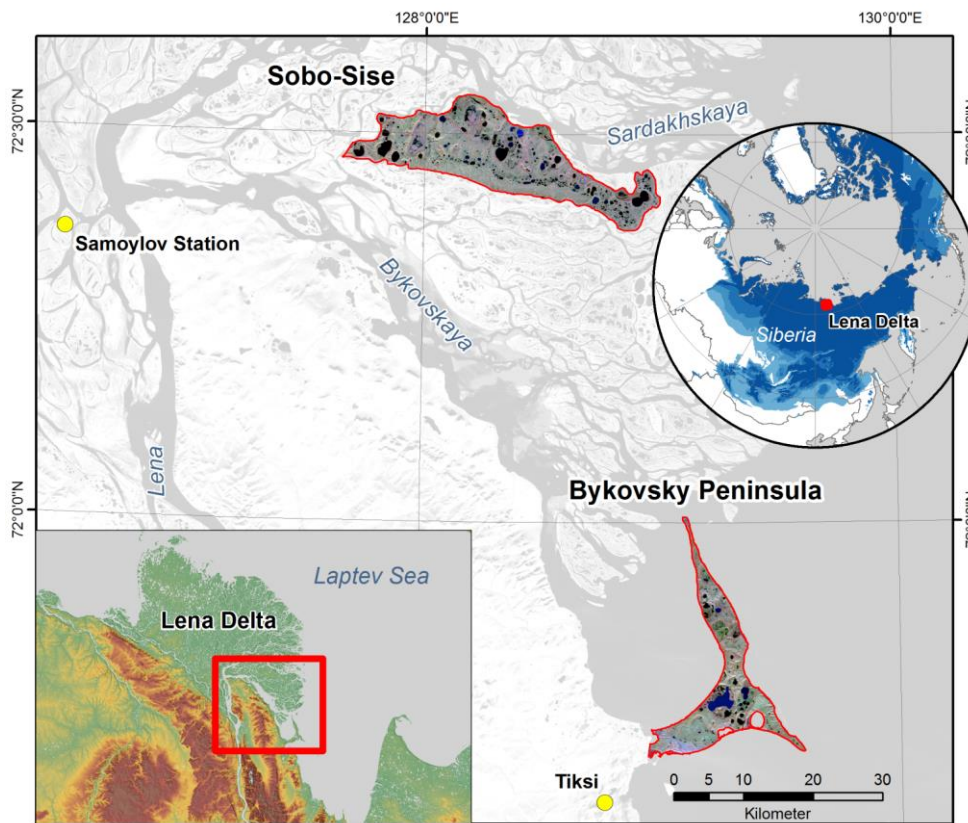
Figure 1: Location of the two study areas in the Lena River Delta region, Sobo-Sise Island and Bykovsky Peninsula (Landsat 5 satellite image, ~~a~~Acquisition date: 19th Sept. 2009). Top right inset: ~~o~~Overview map ~~with~~ including the permafrost zonation in Siberia (after Brown et al., 1997), bottom left inset: ~~Showing the~~the Lena Delta region with a digital elevation model (ESA DUE-Permafrost DEM, Santoro and Strozzi, 2012).
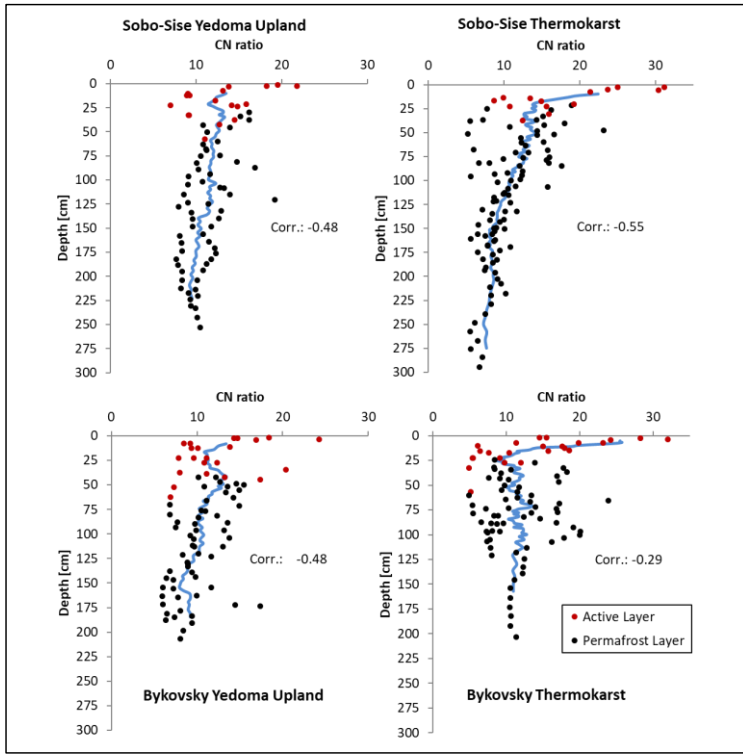
Figure 2: CN ratio for Yedoma upland and thermokarst samples on Sobo-Sise and Bykovsky Peninsula. Blue lines ~~indicating~~ indicate the running mean for the entire sample set (including active layer and permafrost layer samples). The correlation (Pearson correlation) between CN ratio and depth (Corr.) indicates a decreasing CN ratio with increasing depth (p < 0.01).

**Mean SOC [kg C m^{-2}] storage in thermokarst and Yedoma upland deposits on Sobo-Sise and Bykovsky Peninsula**
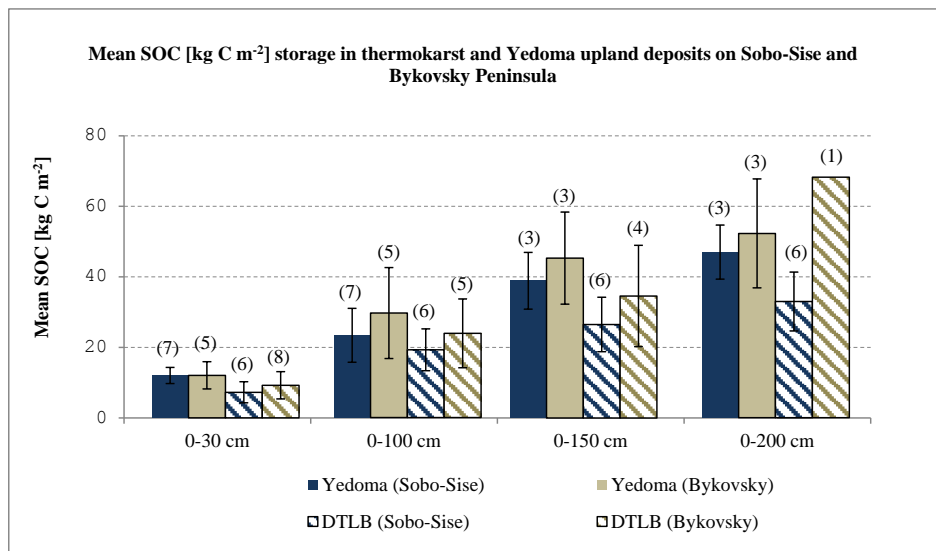
Figure 3: Comparison of mean sampling site SOC storage on Sobo-Sise Island and on Bykovsky Peninsula. Solid bars: Yedoma sites, sStriped bars: Thermokarst sites. Black T-lines show the standard deviation and number in brackets indicate the number of sampled sites. Profiles shorter than 200 cm were extrapolated to the next reference depth. When reaching an ice wedge in a collected site, this was included in the extrapolation as well, assuming no carbon for ice wedge layers. SOC data for this graph are presented in the supplementary material, Table S1 and S4.

Mean nitrogen[kg C m⁻²] storage in thermokarst and Yedoma upland deposits on Sobo-Sise and Bykovsky Peninsula
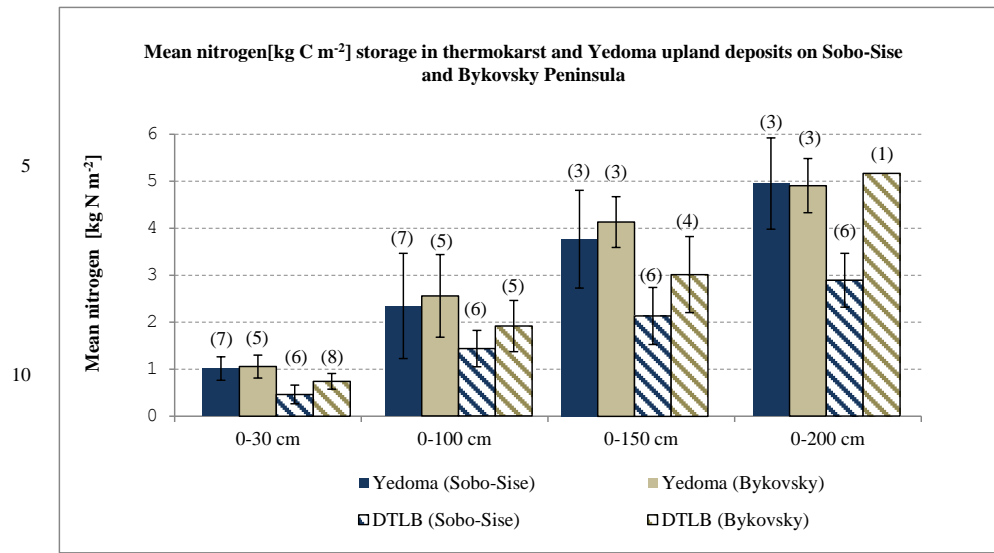
5   **Figure 4:** Mean sampling site N storage for the different geomorphic units in both study areas. Solid bars: Yedoma sites, sStriped bars: Thermokarst sites. Black T-lines show the standard deviation and number in brackets indicate the number of sampled sites. Profiles shorter than 200 cm were extrapolated to the next reference depth. When reaching an ice wedge in a collected site, this was included in the extrapolation as well, assuming no N for ice wedge layers. Soil N data for this graph are presented in the supplementary material, Table S1 and S5.
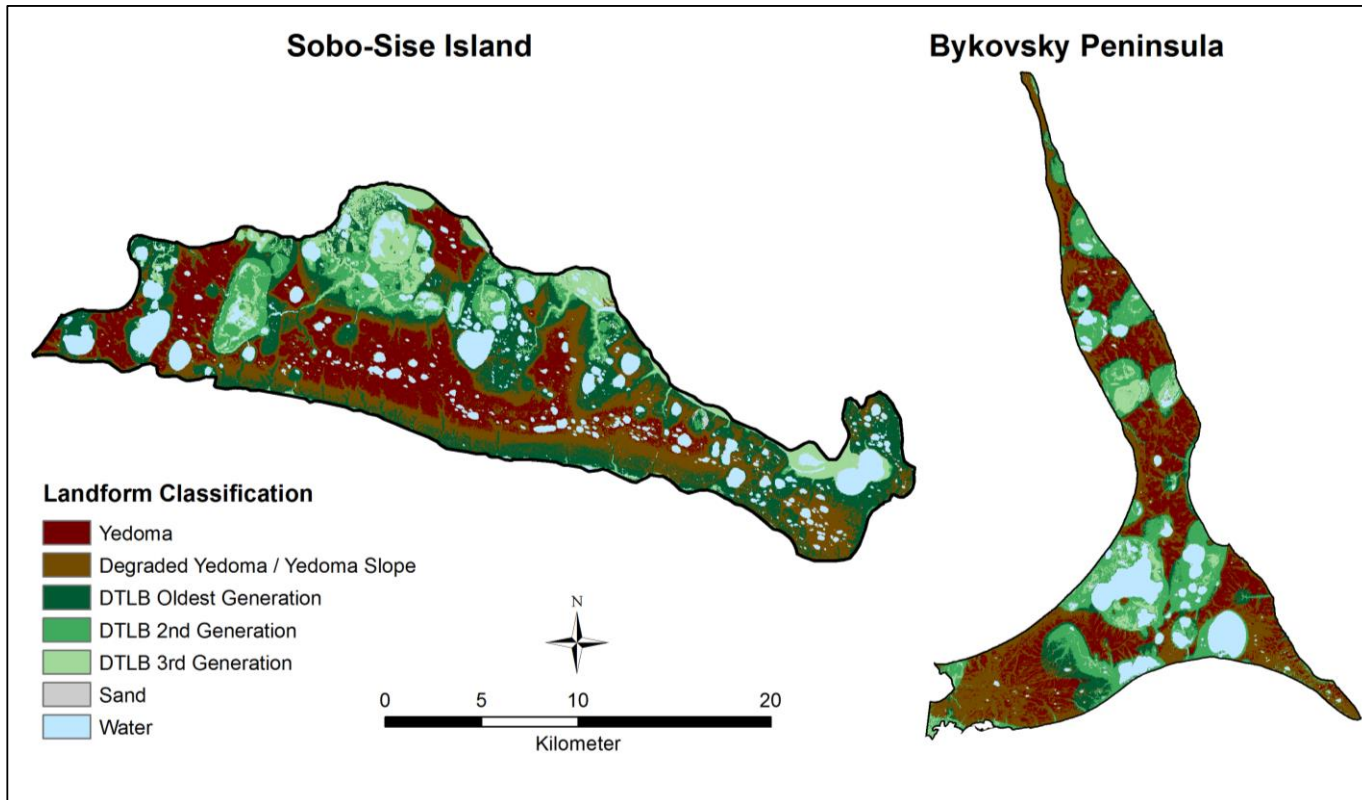
Figure 5: Landform classification of Sobo-Sise Island and Bykovsky Peninsula. For upscaling, the three classes of DTLB generations were merged into a single class 'Thermokarst'.
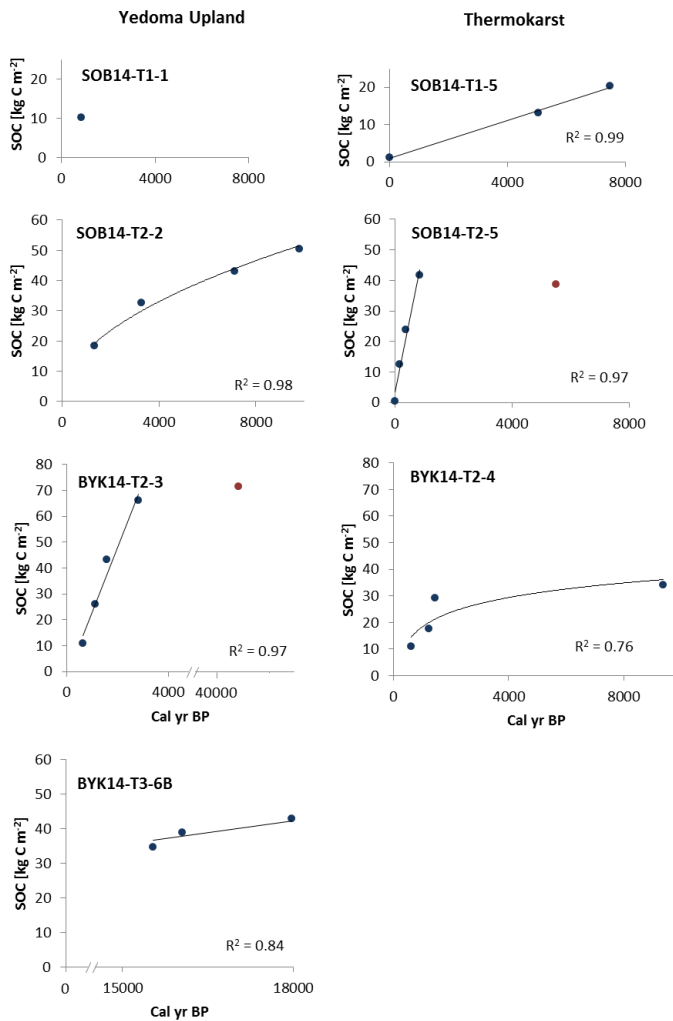
Figure 6: Relationship between cumulative SOC storage ~~with~~ and age. Cal yr BP for radiocarbon dated samples (blue dots) for each core. Lines indicate the best fit correlation of the points excluding outliers (red dots).