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Iuliia Shevtsova[1,2], Stefan Kruse[1], Birgit Heim[1], and Ulrike Herzschuh[1,2,3]

[1] Alfred Wegener Institute (AWI), Helmholtz Centre for Polar and Marine Research, Potsdam, Germany
[2] Institute of Biochemistry and Biology, University of Potsdam, Germany
[3] Institute of Environmental Sciences and Geography, University of Potsdam, Germany

contact e-mail : iuliia.shevtsova@awi.de

ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

RECENT VEGETATION COMPOSITION AND ABOVE GROUND BIOMASS CHANGE IN NORTH-EASTERN SIBERIA

Why is it important?

Climate change is especially prominent in Arctic and sub-Arctic regions. Therefore, it is of great importance to investigate ecosystem processes and the dynamics of its components in the high latitudes. Plant biomass assessment is essential for estimating carbon stocks and further carbon balance and wildlife habitat modelling. Our study region in central Chukotka (north-eastern Siberia) is one of the least investigated sub-Arctic regions in terms of vegetation dynamics.

Central Chukotka: specifics of the study region

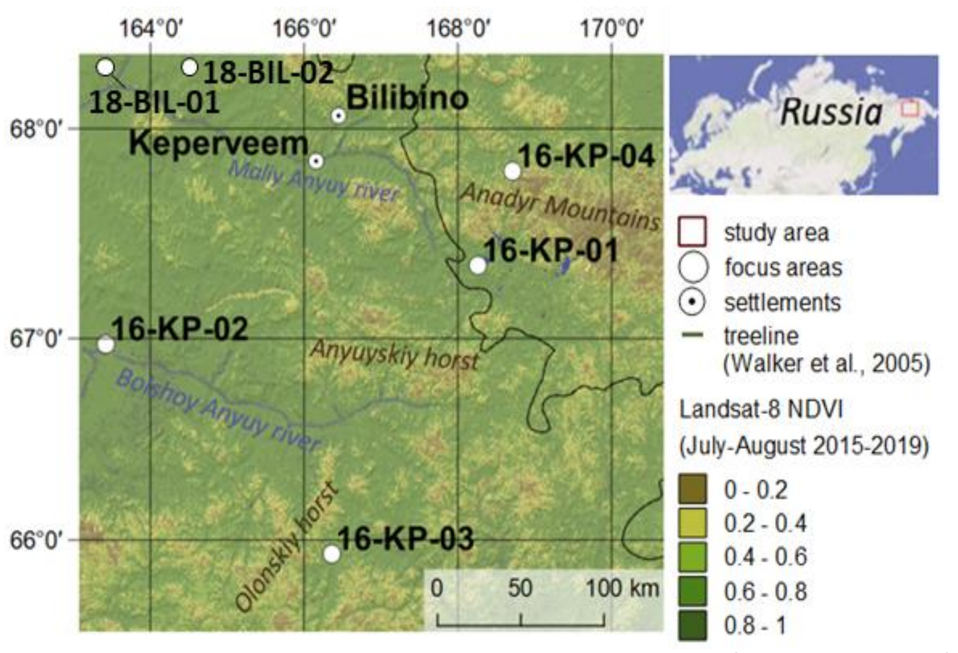


Figure 1. Study region – central Chukotka. (Shevtsova et al., 2020)

Central Chukotka has mountainous terrain. The treeline here is restricted by a combination of elevational and latitudinal limits and formed by deciduous conifer *Larix cajanderi*. Within only 140 km there is a great variety of different vegetation communities. Our focus areas covered a vegetation gradient from treeless tundra (16-KP-04), via tundra-taiga (16-KP-01, 16-KP-03) to northern taiga (16-KP-02). These areas were examined during the Russian-German expedition "Keperveem 2016". In 2018 we additionally investigated 18-BIL-01 and 18-BIL-02 areas and set more sampling plots in 16-KP-01 and 16-KP-04 areas.

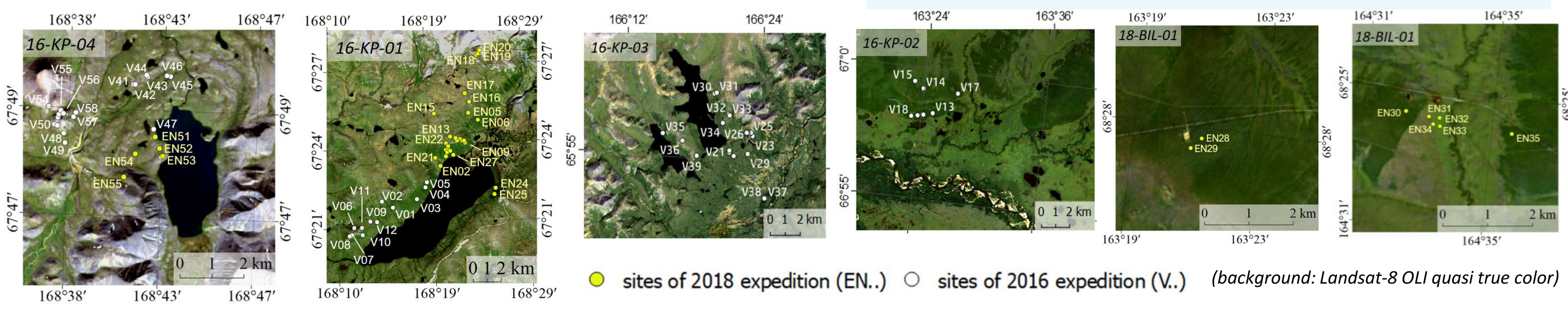


Figure 2. Focus areas (16-KP-04, 16-KP-01, 16-KP-03, 16-KP-02) and additional sampling areas (18-BIL-01, 18-KP-02).

Materials & Methods

Land-cover classification

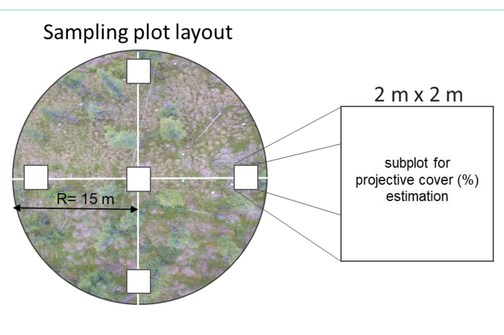


Figure 3. Sampling scheme of 2016 expedition vegetation survey.

During the 2016 expedition foliage projective cover (%) was assessed for different taxa on 52 sampling plots (Fig. 3). For these plots three Landsat spectral indices values were obtained, which were used as predictors in constrained ordination (Redundancy analysis (RDA)), where the predictant was projective cover data (Fig. 4). Ordination scores were used in a k-means classification.

Land-cover change was derived from classified Landsat imagery from recent years (2016 or 2017) and 15-16 years apart (2000, 2001 or 2002; Table 1). We predicted the land-cover classes with the use of Landsat Indices, ordination RDA model and k-means classification.

Table 1. Dates of Landsat aquisitions used in land-cover classification.

Date status / Focus area	recent acquisition	15-16 years older acquisition
16-KP-01	31.07.2016	30.07.2001
16-KP-02	12.08.2016	08.08.2000
16-KP-03	31.07.2016	30.07.2001
16-KP-04	10.08.2017	09.08.2002

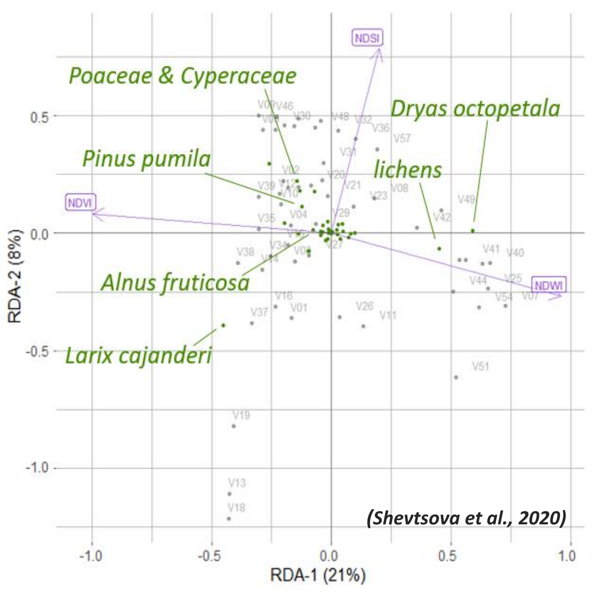


Figure 4. Redundancy analysis (RDA) plot with Landsat Indices (NDVI, NDWI, NDSI) as predictors and major taxa as predictants displayed.

Landsat spectral Indices

Before Indices deriviation cloud-free Landsat-8 OLI acquisitions were topographically corrected and transformed into Landsat-7 ETM+-like (band by band). Surface waters were masked out.

Three spectral Indices were calculated:

The vegetation Indices NDVI and NDWI from peak-summer (15 July-15 August) aquisitions, the snow Index NDSI – from snow-covered acquisitions (March).

Normalised Difference Vegetation Index,

$$NDVI = \frac{NIR-RED}{NIR+RED},$$

Normalised Difference Water Index,

$$NDWI = \frac{GREEN-NIR}{GREEN+NIR},$$

Normalised Difference Snow Index,

$$NDSI = \frac{GREEN-SWIR1}{GREEN+SWIR1}.$$

Above ground biomass sampling and prediction

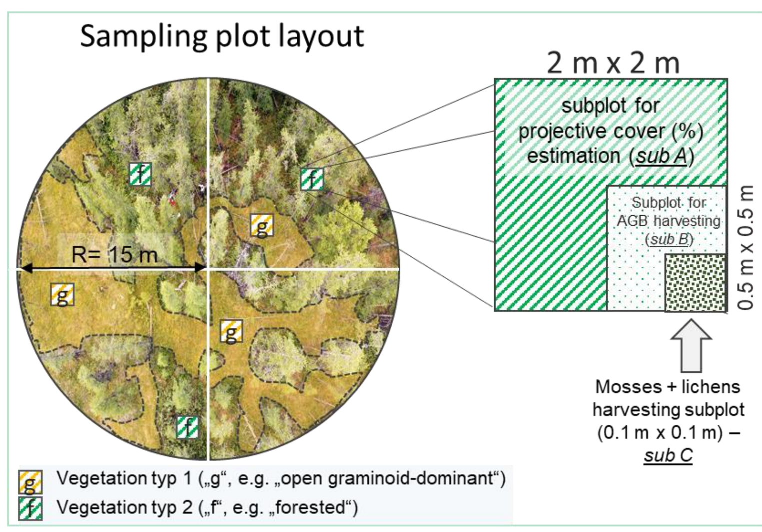


Figure 6. Sampling scheme of 2018 expedition vegetation survey. To account for heterogeneity in the main sampling plot with radius 15 m two to three dominant vegetation types were roughly estimated, e.g. we placed two types as shown („g" and „f"). Within every vegetation type three sampling subplots (sub A, 2 m x 2 m) were placed for projective cover assessment. Inside one of most representative subplot sub A per vegetation type we placed subplot sub B (0.5 m x 0.5 m) for harvesting above ground biomass (AGB) from the ground layer plants, excluding mosses and lichens, for which we placed representative smaller subplot sub C (0.1 m x 0.1 m) for biomass harvesting.

During the Russian-German expedition „Chukotka 2018" projective cover (%) and above ground biomass (AGB) were estimated on 38 sampling plots, using the sampling scheme shown on Fig. 6. All biomass samples were weighted in fresh state in the field. Biomass samples more than 10-15 g were subsampled. Then all subsamples were oven dried (60°C) and weighted again.

Tree AGB (*Larix cajanderi*) sampling included sampling of living branches, dead branches, needles, cones and tree stem discs from three representative trees for each sampling plot. Furthermore, heights for all trees on the sampling plots were noted. Thus using an exponential model (total biomass of sampled trees ~ height) we reconstructed AGB of each tree on the plot. Summarised AGB form all trees was recalculated in kg/m².

Ground layer and shrub AGB was reconstructed using individual plant biomass and projective cover of the taxa on the sampling plot. To account for heterogeneity three biomass sampling subplots were placed into every area of visually different vegetation community. Biomass from this plots was averaged and recalculated in kg/m².

The sites of 2018 expedition were projected into the ordination space, ceated before, using the 2016 expedition data. Land-cover classes were predicted as well. To map total AGB we built a general additive (GAM) model:

$$\text{Total AGB} = \text{RDA1} + s\,(\text{RDA1}, \text{RDA2}),$$

RDA1, RDA2 – ordination scores of first and second axes respectively,
s – Smooth monotonic function.

Landsat scenes were used together with GAM model to predict total AGB in four focus regions in recent time and 15-16 years apart.

Results

Land-cover classes

We derived four stable land-cover classes with different vegetation composition (Fig. 7).

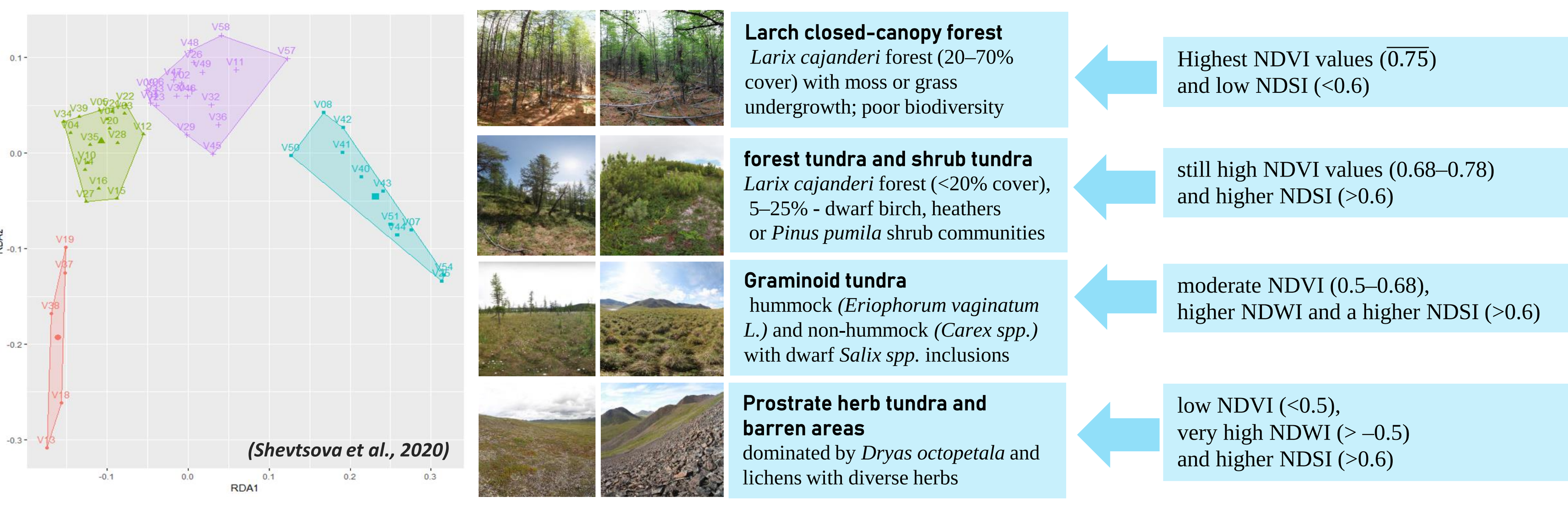
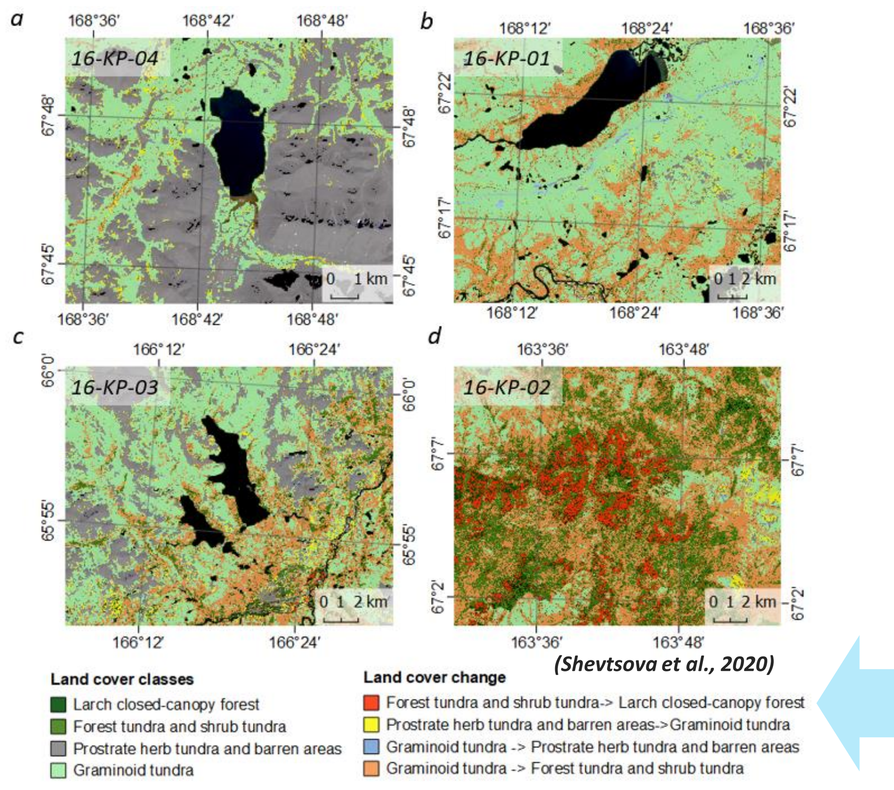


Figure 7. Land-clover classes (derived by k-means method) based on two RDA axes and general vegetation description for each land-cover class.

Land-cover change



Land-cover change was different for in the four investigated areas of different ecological regions (Fig. 8):

- **treeless tundra** (16-KP-04 between 2002 and 2017) stayed rather stable.
- **tundra-taiga ecotone** (16-KP-01 and 16-KP-03 between 2001 and 2016) experienced 20–25% increase in area of forest tundra and shrub tundra (interpreted as shrubification).
- **northern taiga** (16-KP-02 between 2000 and 2016) had greatest changes: expansion of larch closed-canopy forest (9%, interpreted as tree infilling) and vast increase of forest and shrub tundra (40%, interpreted as shrubification).

Figure 8. Colour-coded land-cover classes and colour-coded land-cover change: a) 16-KP-04 (treeless tundra), b) 16-KP-01 (tundra–taiga transition), c) 16-KP-03 (tundra–taiga transition) and d) 16-KP-02 (northern taiga).

Above ground biomass

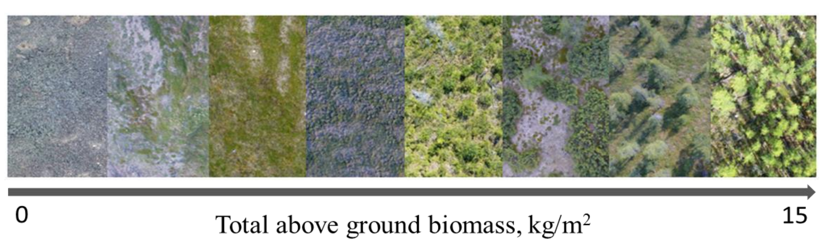


Figure 9. Range of AGB from 0 kg/m² in barren areas to 15 kg/m² in larch closed-canopy forest. Images made using drone from 30 m flight height.

Above ground biomass within all examined sampling plots from treeless tundra via tundra-taiga to northern taiga ranges from 0 to 15 kg/m² (Fig. 9)

Largest contributors to AGB are (Fig. 10):

- in larch closed-canopy forest - *Larix cajanderi* in the overstorey, mosses and lichens and *Betula exilis* in the understorey.
- in forest tundra and shrub tundra – *Larix cajanderi* in the overstorey, mosses and lichens, *Vaccinium vitis-idaea* and *Ledum palustre* in the understorey.
- in graminoid tundra – mosses and lichens, grasses and forbs (other) and some dwarf shrubs (*Salix spp., Betula exilis, Ledum palustre*).
- in prostrate herb tundra – *Dryas octopetala*.

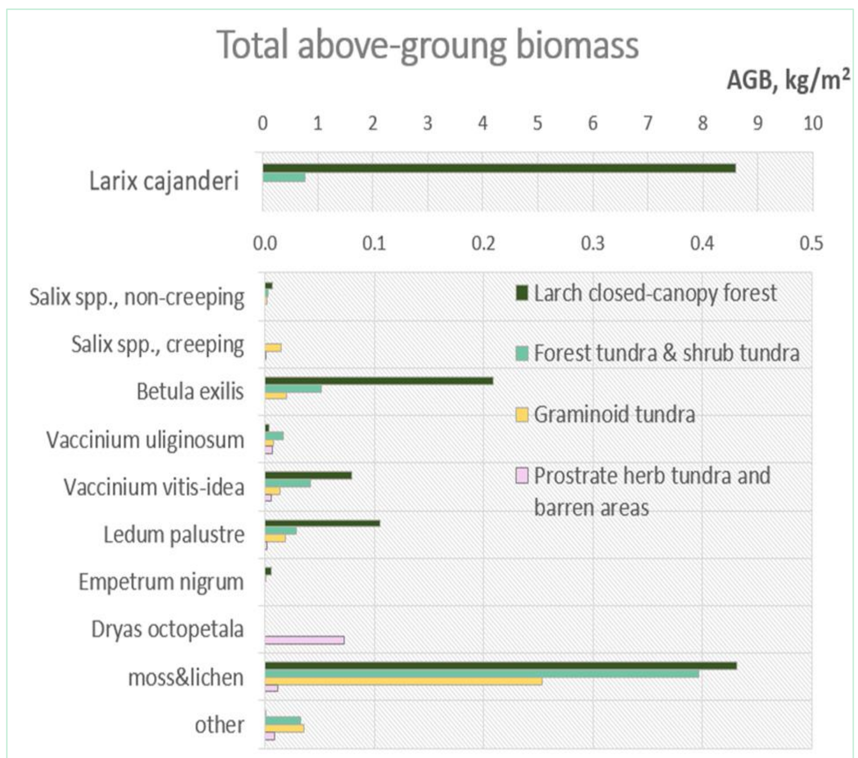


Figure 10. Total AGB of different taxa in four land-cover classes.

Above ground biomass change

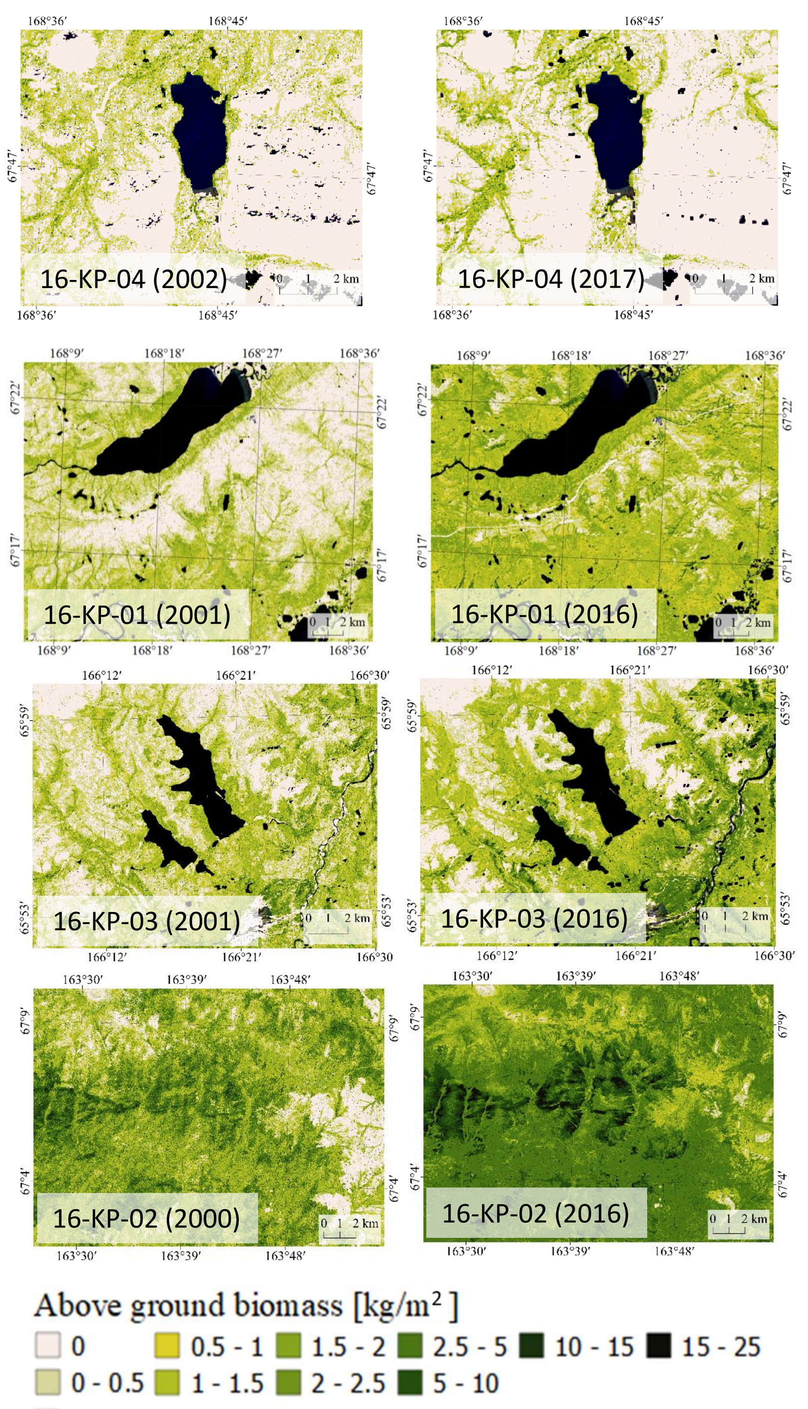


Figure 11. Total AGB state in recent years (2000, 2001 or 2002) and former years (2016 or 2017) in four focus regions: 16-KP-04 (treeless tundra), 16-KP-01 (tundra–taiga, northern), 16-KP-03 (tundra–taiga, southern) and 16-KP-02 (northern taiga).

Total AGB of the **treeless tundra** (16-KP-04) area ranged from 0 to 3 kg/m². 55% (2002) or 63% (2017) of areas are non-vegetated (0 kg/m² AGB). AGB in prostrate herb tundra in average decreased from 0.12 to 0.03 kg/m² within investigated period (2002-2017); in graminoid tundra – stayed rather stable (increase 0.51 to 0.56 kg/m²). **Shrub encroachment** ("graminoid tundra" class turned into "forest tundra & shrub tundra" class) resulted in average **0.24 kg/m² AGB increase** (from 1.34 to 1.58 kg/m²). In contrast, class change from prostrate herb tundra to graminoid tundra resulted in 0.25 kg/m² decrease in AGB (from 0.37 to 0.12 kg/m²).

Total AGB of the **northern tundra-taiga** (16-KP-01) area ranged from 0 to 12 kg/m². 25% (2001) or 3.5% (2016) of areas are non-vegetated (0 kg/m² AGB). AGB in prostrate herb tundra in average stayed stable 0.18-0.19 kg/m² within investigated period (2001-2016); in graminoid tundra – increased from 0.37 to 1.34 kg/m² ; in **forest and shrub tundra** – increased **from 1.48 to 2.61 kg/m²**. Prostrate herb tundra change into graminoid tundra resulted in 0.14 kg/m² AGB increase (0.1 to 0.24 kg/m²). Switch from graminoid tundra to forest tundra and shrub tundra resulted also in average 0.14 kg/m² AGB increase (1.21 to 1.35 kg/m²).

Total AGB of the **southern tundra-taiga** (16-KP-03) area ranged from 0 to 19 kg/m². 22% (2001) or 15% (2016) of areas are non-vegetated (0 kg/m² AGB). AGB in prostrate herb tundra in average decreased slightly from 0.23 to 0.18 kg/m² within investigated period (2001-2016); in graminoid tundra – increased from 0.56 kg/m² to 1.24 kg/m² ; in **forest and shrub tundra** – increased **from 2.03 kg/m² to 3.57 kg/m²**. Prostrate herb tundra turned into graminoid tundra resulted in 0.37 kg/m² AGB increase (0.38 to 0.75 kg/m²). Switch from graminoid tundra to forest tundra and shrub tundra resulted in average 0.47 kg/m² AGB increase (1.34 to 1.81 kg/m²). The major AGB change is associated to **forest tundra and shrub tundra turned into larch closed-canopy forest** with a **6.55 kg/m² AGB increase** (from 3.10 to 9.65 kg/m²).

Total AGB of the **northern taiga** (16-KP-02) area ranged from 0 to 24 kg/m². 7% (2000) or 0.3% (2016) of areas are non-vegetated (0 kg/m² AGB). AGB in prostrate herb tundra in average increased from 0.10 to 0.21 kg/m² within investigated period (2000-2016); graminoid tundra – increased from 0.69 kg/m² to 1.85 kg/m²; in forest and shrub tundra – increased from 2.48 kg/m² to 3.17 kg/m²; in **larch closed-canopy forest** – increased from **8.41 kg/m² to 10.41 kg/m²**. Prostrate herb tundra turned largely into graminoid tundra and resulted in 1.05 kg/m² AGB increase (0.08 to 1.12 kg/m²). Even more areas went from graminoid tundra to forest tundra and shrub tundra and resulted in 1.45 kg/m² AGB increase (1.27 to 2.72 kg/m²). Some areas of **forest tundra and shrub tundra class turned into larch closed-canopy** class which resulted in **5.80 kg/m² AGB increase** (2.87 to 8.67 kg/m²).

Conclusions

Changes in above ground biomass are not only associated with changes in land-cover classes, but also observed within areas with no changes in land-cover class. That could indicate either land-cover changes that still are not prominent enought to trigger land-cover class change, or change in plant properties (height, crone diameter, leaf size etc.) within the investigated period. AGB changes differ from one eclological region to another (tundra/tundra-taiga/northern taiga). The greatest changes occured in northern taiga, particulary in the larch closed-canopy forest class, which also has highest AGB.

References:

Shevtsova, I., Heim, B., Kruse, S., Schröder, J., Troeva, E., Pestryakova, L., Zakharov, E., Herzschuh, U. Strong shrub expansion in tundra-taiga, tree infilling in taiga and stable tundra in central Chukotka (north-eastern Siberia) between 2000 and 2017, Environmental Research Letters, 2020 (accepted: https://doi.org/10.1088/1748-9326/ab9059)

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