4 May 2020

KOUGAROK VEGETATION DATA SUMMARY FOR ELM

Verity Salmon (salmonvg@ornl.gov)

Vegetation data was collected in the summary of 2016 and 2017 at the NGEE Arctic Kougarok field site on the Seward Peninsula. Data summarized includes plant biomass, net primary production, and other plant traits necessary for parameterizing the ELM model. Site specific data for Kougarok was used whenever available and literature values were used to fill in missing values as necessary. This document details calculations and literature references for this data set. The data in this dataset (compiled 12 June 2019) differs from previous versions because it contains data on a plot-by-plot basis rather than averaged per plant community/Ecotype.

1. Overview

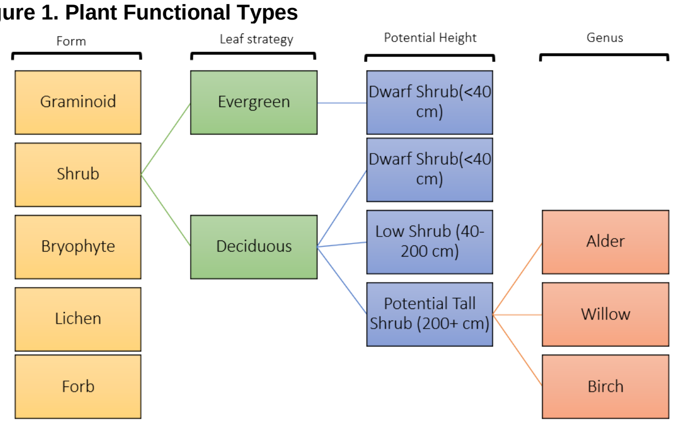
Ecotypes are defined as distinct plant communities paired with their unique environmental conditions. Some plant species occur across several of the ecotypes.

Table 1. Ecotype descriptions

Abbreviation	Ecotype	Notes
AS	Alder shrubland	Dominated by tall alder
DSLT	Dwarf shrub lichen tundra	Short stature, dry shrubby community on well drained slopes of hill
NAMC	Non-acidic mountain complex	Rocky, exposed community at top of hill. Very little vegetation, lots of lichen
TT	Tussock Tundra	Moist, Graminoid and moss dominated communities along toeslope of hill
TTWBT	Tussock Tundra Willow Birch Tundra	Mixture of TT and WBT communities, short alder present. Water draining downhill through these communities
WBT	Willow Birch Tundra	Mid stature shrubby communities

The following plant functional types were used to group data from the field and literature: graminoid, bryophyte (mosses and liverworts), lichen, forb, dwarf shrub evergreen, low shrub evergreen, dwarf shrub deciduous, low shrub deciduous, potential tall deciduous shrub alder, willow, and birch. A “mixed” PFT was added to describe the fine root biomass pool since it was not possible to differentiate between roots of the various PFTs during sampling. We had discussed separating graminoids into wet and dry graminoid PFTs but in the 2016 dataset we had several unknown species of graminoid which makes differentiating between the two difficult.

Figure 1. Plant Functional Types



The following table designates which the PFTs assigned were assigned to the plant species. Note that shrub types were generally separated by their maximum height potential, as specified in the USDA plant database or Flora of North America. The PFT group “potential tall shrubs” must be handled with care and should not be used interchangeably with “tall shrubs”. Arctic vegetation literature does not typically group shrub species by potential height, tall shrubs usually refers to actual height (see Macander et al., 2017; Swanson, 2015).The only species at Kougarok to grow over 200cm is Alder.

Table 2. Plant Functional Types for all species

Species Code	Genus	Species	Subspecies	ELM PFT	Notes
ALNFRU	Alnus	viridis	fruticosa	potential tall shrub deciduous alder	
ANDCHA	Androsace	chamaejasme	NA	forb	
ANDPOL	Andromeda	polifolia	NA	dwarf shrub evergreen	
ARCALP	Arcous	alpina	NA	dwarf shrub evergreen	
BETGLA	Betula	glandulosa	NA	potential tall shrub deciduous birch	
BETNAN	Betula	nana	NA	low shrub deciduous	Changed from dwarf shrub deciduous 4May2020
CARBIG	Carex	bigelowii	NA	graminoid	
CARMIC	Carex	microchaeta	NA	graminoid	
DRYOCT	Dryas	octopetala	NA	dwarf shrub evergreen	
EMPNIG	Empetrum	nigrum	NA	dwarf shrub evergreen	
EQUARV	Equisetem	arvense	NA	forb	Horsetail fern, non-flowering plant
ERIVAG	Eriophorum	vaginatum	NA	graminoid	
HIEALP	Hierochloe	alpina	NA	graminoid	
LEDPAL	Ledum	palustre	decumbens	dwarf shrub evergreen	alternate name Rhododendron tomentosum s. decumbens
lichen	NA	NA	NA	lichen	species not identified
liverwort	NA	NA	NA	Bryophyte	species not identified
LOUPRO	Loiseleuria	procumbens	NA	dwarf shrub evergreen	
moss	NA	NA	NA	Bryophyte	species not identified
OXYSPP	Oxytropis	species	NA	forb	
RUBCHA	Rubus	chamaemorus	NA	forb	RUBCHA sometimes characterized as woody in other Arctic datas
SALALA	Salix	alaxensis	NA	potential tall shrub deciduous willow	
SALGLA	Salix	glauca	NA	potential tall shrub deciduous willow	
SALPUL	Salix	pulcra	NA	low shrub deciduous	
SALRIC	Salix	richardsonii	NA	potential tall shrub deciduous willow	
VACOXY	Vaccinium	oxycoccus	NA	dwarf shrub evergreen	
VACULI	Vaccinium	uliginosum	NA	low shrub deciduous	Changed from potential tall shrub decidous willow 4May2020
VACVIT	Vaccinium	vitis-idaea	NA	dwarf shrub evergreen	
unknown forb	NA	NA	NA	graminoid	species not identified
unknown graminoid	NA	NA	NA	graminoid	species not identified

2. Data: Plant Biomass and Net Primary Productivity

All plant biomass and NPP data from the field were collected at n=2 plots per ecotype (12 plots total)

a. Aboveground Biomass and NPP

Understory Species

Understory aboveground biomass was sampled using small, 20 x 50 cm clip plots. The understory sampled included nonvascular plants, lichen, graminoids, forbs, and dwarf shrub species (including *Betula nana* and *Vaccinium uliginosum*). All material from understory clip plots was cut at the level of the moss or soil surface. Some material was sorted within 1-2 days of collection in the UAF lab facility in Nome, but most material was frozen, shipped, and sorted at ORNL. Whenever possible, current year stem and leaves were separated from older materials and treated as separate samples for quantification of NPP. For woody plants, this often meant looking for new stem material with bark was lighter in color and more pliable than the older tissue. Only live materials were included in this data summary. Live moss was distinguished from dead based on color: green moss was considered live.

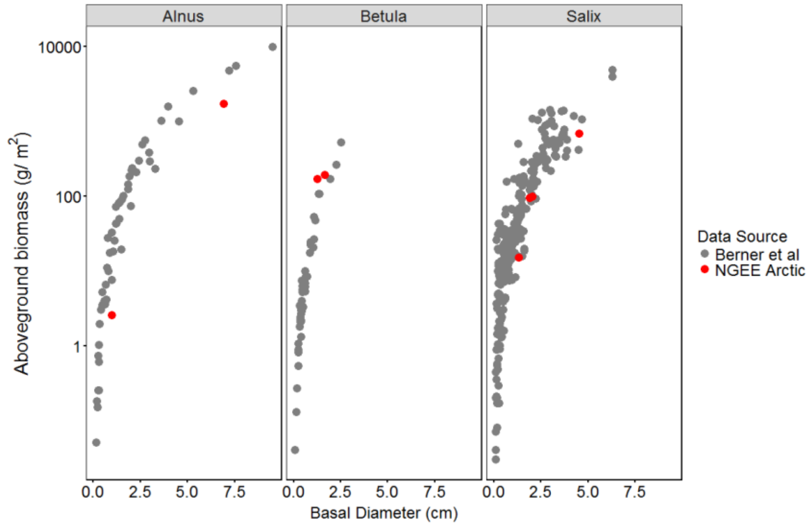
Live liverworts were sorted and combined with live mosses for bryophyte PFT. All discernable lichen material was considered live. After sorting, all materials were dried in an oven at 70°C for 1-2 days and weighed for dry biomass.

Net primary productivity was calculated based on new versus old tissues. Graminoids were assumed to be deciduous, with a leaf pool turning over annually. Some arctic sedges are known to have leaves that over winter and continue growing the next year so this assumption may need to be revisted (Shaver and Laundre, 1997).

Tall Shrub Species

To quantify the biomass of tall shrub species, we surveyed larger vegetation plots (2.5m x 2.5m and 5m x 5m) for the presence of *Alnus viridiris* ssp *fruticosa, Betula glandulosa, Salix alaxensis, Salix glauca, Salix pulcra,* and *Salix richardsonii*. For all individuals of these species in the plot we noted species, measured the max height, and measured the basal diameter of all stems at the ground level. When the stem was not uniformly round we measured basal area twice and took an average. We then performed a destructive harvest of one individual for each of the tall shrub species present in the plot to determine whether existing allometries could be applied at this site. During the destructive harvest of these tall shrub species, we separated attached dead leaves, inflorescences, live leaves, attached dead wood, live wood, and current year's stem growth in the field. Stem growth of current year was differentiated from old stem growth by the absence of healed leaf bud scars and lighter color bark. While in the field, we measured total fresh weight of live and dead wood using hanging scales and subsamples of these tissues were brought back to the lab. These samples were weighed before and after being dried in an oven to determine % water content for live and dead wood. The water weight in live and dead wood was then subtracted from the field weights of these tissue to get the total dry weight of live and dead wood. After sorting, all plant tissues were dried in an oven at 70°C for 1-2 days and weighed. The total aboveground biomass numbers from these harvested shrubs were found to be within the range of existing allometric relationships (See Fig 2. Below and Berner et al., 2015). Given this agreement, we used Berner et al's allometric equations for aboveground biomass and NPP for the tall shrubs we surveyed (but did not harvest). The allometric relationships in Berner et al do not consider secondary stem growth (thickening of existing stems) and do separate leaf biomass from stem biomass. We therefore used the ratio of leaves to the sum of new leaves plus stem observed in our harvests to separate leaf and stem biomass for all tall shrubs. The ratios in our data (0.80-0.87) were similar to those that Berner observed in a subset of his data (0.80, personal communication). We assumed that leaf NPP for tall shrubs would consist of the entire leaf pool since all the tall shrubs are deciduous. Stem NPP is the sum of primary stem NPP (extension of new stem) plus secondary stem NPP (thickening of existing stems). Primary stem NPP was calculated as the NPP from Berner's allometric equations minus the leaf NPP. Secondary stem NPP was calculated based on ratios of secondary stem growth to primary stem growth observed for Salix and Betula in Bret-Harte et al's study from Toolik Arctic LTER (Bret-harte et al., 2002). The ratio applied to Alder was an average of Salix and Betula.

Fig 2. Allometric relationships from NGEE Arctic harvests and Berner et al.



b. Belowground Biomass and NPP

Fine Root biomass

Fine root biomass was measured on n=2 soil cores collected within each of the biomass plots (n= 2 per ecotype). In the field, soil cores were separated into depth intervals of roughly 10cm. The soil corer used had a diameter of 7.62 cm and cores were taken until we hit rock or permafrost. Soil samples were frozen and shipped to ORNL for processing. In the lab, intact core samples were split vertically in half while samples that lacked any remaining structure were divided in half on a weight basis. One half of each core was used to determine soil properties (Data available on NGEE Arctic portal). The remaining half had all live fine roots (<2mm diameter) carefully removed, scanned and weighed. Only live roots were quantified and dead roots were identified as those that were 1) visibly ragged, hollow or flat (presumably due to from decomposition) 2) offered no resistance to being pulled apart by tweezers. Due to the potential presence of aerenchyma in some species present, floating roots were not considered dead. For some ecotypes (TT,WBT, DSLT) the extensive volume of fine roots and the matted, dense soil organic matter made picking half a core within one week of thaw impossible. In these instances, a smaller subsample was picked and scaled up.

Note: fine roots could not reliably be attributed to specific PFTs. We therefore listed all fine root biomass to a separate “Mixed” PFT within each of the ecotypes.

Fine Root Net Primary Productivity

Fine root primary productivity was not measured at Kougarok so we used the turnover time observed within similar arctic plant communities to estimate this flux (Aerts et al., 1992; Ruess et al., 1996; Shaver and Billings, 1975; Sullivan et al., 2007)

Table 3. Fine root turnovers in arctic literature

Ecotype	Fine Root Turnover (years)	Notes
AS	1.33	Ruess et al 1996, sequential soil cores collected in interior AK Alder-Balsam poplar stand
DSLT	1.56	Aerts et al 1992 from sequential cores in a dry heathland in the Netherlands (evergreen dwarf species)
NAMC	1.56	Aerts et al 1992 from sequential cores in a dry heathland in the Netherlands (evergreen dwarf species)
TT	3.13	Sullivan et al 2007, from fine root biomass pools and minirhizotrons in tussock tundra at Toolik. Shaver 1975 estimates from Barrow have turnover time of 4 years but for wet sedge tundra. Tundra at our site is more similar to Toolik plant community so Sullivan's is more applicable
TTWBT	2.23	Average of Ruess et al 1996 Alder-Balsam popular and Sullivan 2007 Oeologia tussock tundra number
WBT	1.33	Ruess et al 1996, sequential soil cores collected in interior AK Alder-Balsam poplar stand

Rhizome Biomass

Rhizome biomass (belowground stems) were not measured at Kougarok. Soil cores sorted for fine roots were too small of a sample to reliably estimate rhizomes and aboveground clip plots and surveys did not capture this pool. We therefore calculated rhizomes based on relationships between aboveground biomass and rhizomes for PFTs and plant communities observed at Toolik Lake (Shaver and Chapin, 1991). The Kougarok TT ecotype was considered similar to Shaver's tussock tundra community, DSLT and NAMC ecotypes were considered similar to Shaver's heath community, and AS and WBT ecotypes were considered similar to Shaver's shrub vegetation type. The TTWBT ecotype is a mixture of shrubs and tussocks so Shaver's Tussock tundra rhizome: aboveground was applied to TTWBT graminoids while Shaver's shrub rhizome: aboveground was applied to TTWBT shrubs.

Table 4. Ratio of Rhizome biomass to aboveground biomass in Shaver & Chapin 1991

	Rhizome Biomass :Aboveground Biomass		
PFT	**Tussock Tundra Community**	**Shrub Community**	**Heath Community**
Graminoid	0.91	0.36	1.40
Deciduous	1.51	1.07	1.36
Evergreen	1.41	0.17	0.88
Forb	0.89	0.51	NA
All vascular	1.29	1.05	0.99

Rhizome Net Primary Productivity

Rhizome NPP was not measured at Kougarok. In Shaver 1991, graminoid rhizome productivity was measured based on inter-node biomass increments. A new node forms on the rhizome for each tiller produced so the internode biomass was then scaled to annual tiller production numbers and measurements of tiller density. We used their community-specifics ratios of leaf NPP: rhizome NPP to calculate rhizome NPP for graminoids at Kougarok. For non-graminoids, we calculated the turnover of stem biomass in the Kougarok dataset (stem biomass/ stem npp) and assumed that the turnover of rhizomes would be the same.

Table 5. Turnover of stems, calculated from aboveground stems and applied to rhizomes. Note this table was updated 4May2020 to reflect updated PFT designations for species aboveground biomass and NPP.

Ecotype	PFT	Stem Turnover (years)
AS	dwarf shrub evergreen	26.55
AS	low shrub deciduous	25.72
AS	potential tall shrub deciduous alder	100.02
AS	potential tall shrub deciduous birch	29.78
TTWBT	dwarf shrub evergreen	13.96
TTWBT	low shrub deciduous	22.14
TTWBT	potential tall shrub deciduous alder	80.30
TTWBT	potential tall shrub deciduous willow	42.47
WBT	dwarf shrub evergreen	9.58
WBT	low shrub deciduous	22.97
WBT	potential tall shrub deciduous birch	21.73
WBT	potential tall shrub deciduous willow	92.11
DSLT	dwarf shrub evergreen	24.63
DSLT	low shrub deciduous	21.62
TT	dwarf shrub evergreen	13.18
TT	low shrub deciduous	13.81
TT	potential tall shrub deciduous willow	33.60
NAMC	dwarf shrub evergreen	6.25

3. Data: Tissue Chemistry & leaf SLA

a. Foliar Data

Leaves in understory clip plots, shrub harvests, and alder were sampled in 2016 and 2018. Foliar %C and %N by weight and specific leaf area (cm^2 per g dry leaf) are summarized here. Across all samples (new and old leaves, sun and shade leaves) were averaged for each PFT present within the ecotypes at Kougarok. Within a few communities, no forb samples were large enough to process for SLA or chemistry. In these instances, average forb SLA and foliar %C and %N across the entire Kougarok dataset were substituted.

b. Stem & Rhizome Data

Stems and rhizomes were not run for percent C and N. Percent N data from Shaver et al 1991 was compiled and averaged to gapfill this data. The Kougarok TT ecotype was considered similar to Shaver's tussock tundra community, DSLT and NAMC ecotypes were considered similar to Shaver's heath community, and AS and WBT ecotypes were considered similar to Shaver's shrub vegetation type. The TTWBT ecotype is a mixture of shrubs and tussocks so graminoid and forb rhizome and stem N were taken from Shaver's tussock tundra community while shrub values were taken from Shaver's shrub community. Average PFT stem and rhizome %N values across the entire Shaver study were substituted when community specific data was not available.
Stem and rhizome percent carbon was assumed to be 50%. Literature values can be substituted here in the future if need be.

Table 6. Rhizome and Stem %N summarized from Shaver et al 1991.

Community	ELM group	StemN_percent	RhizomeN_percent
Shrub	Betula	1.36	0.68
Shrub	deciduous	0.94	0.72
Shrub	forb	1.87	NA
Shrub	Salix	0.99	0.57
Shrub	graminoid	NA	1.34
Heath	Betula	1.67	NA
Heath	deciduous	1.06	0.71
Heath	evergreen	1.07	0.72
Heath	graminoid	1.69	0.68
Heath	Salix	1.53	0.59
Tussock Tundra	Betula	1.56	0.62
Tussock Tundra	deciduous	0.98	0.68
Tussock Tundra	evergreen	1.04	0.67
Tussock Tundra	forb	1.16	0.92
Tussock Tundra	graminoid	NA	1.02
Tussock Tundra	Salix	0.95	NA
Wet Sedge	forb	1.53	1.00

c. Fine Root Data

We are currently waiting for analysis %C and %N of fine root samples from Kougarok. Literature values for arctic species present in the ELM PFTs are summarized below (Chen et al., 2002; Iversen et al., 2015). For now, fine roots are assumed to have 1.3 %N (average across all PFTs in our dataset) and a fine root C to N ratio of 42 (global average across all PFTs with FRED database, Iversen et al., 2017).

Table 7. Fine root %N for arctic PFTs

PFT	Minimum fine root %N	Maximum fine root %N	Mean fine root %N	Source
Salix	0.5	1.5	1	Iversen et al 2014
Betula	0.4	2	1.2	Iversen et al 2014
Alder spp	NA	NA	1.8	Chen et al 2002
evergreen shrub	0.6	1.6	1.1	Iversen et al 2014
decididuous shrub	0.4	1.3	0.85	Iversen et al 2014
graminoid	0.5	2.8	1.65	Iversen et al 2014
forb	1.1	2.1	1.6	Iversen et al 2014

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