Annual veg change on the ARCSS subplots at Atqasuk and Utqiaġvik, Alaska

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The vegetation of the Arctic is expected to change as the region warms and these changes may influence global climate. This study documents vegetation change across tundra plant communities at Utqiaġvik and Atqasuk, Alaska (FIG. 1). At each location 30 1m² plots, distributed equally across the landscape, were sampled annually, *via* a point-frame method, from 2010 to 2019 (FIG. 2) in a manner similar to those described in Botting (2015). Plant specimens were identified to species and lumped into the following taxonomic groups: deciduous shrubs, evergreen shrubs, forbs, graminoids, bryophytes and lichens. Standing dead vegetation and leaf litter were also included. The change in vegetation was compared with changes in the following abiotic factors: year, air temperature, soil temperature, degree day sums (calculated from air temperature), thaw depth, soil moisture, and precipitation.

Across years there were significant differences in plant cover and height. (FIG. 3, Table 1, Table 2). General linear mixed models (Table 1) and Bayesian regression analysis (Table 2) between abiotic factors and plant cover provide insights into the relationships between the growth and abundance of growth forms and abiotic variables.

Overall, changes in vegetation are occurring at both Atqasuk and Utqiaġvik, many of which concur with other research findings (Elmendorf *et al*. 2012; Hollister *et al*. 2015). Yearly observations from the seven sampling periods since 2010, as well as correlation values obtained from this study suggest that some observed changes are directional over time and are due at least in part to climate influences.

Long-term monitoring is necessary to document change and understand the complexity of the many potential drivers of these observed changes. Continued monitoring is necessary for higher resolution relationships between vegetation growth forms and abiotic variables.

Documenting and understanding vegetation change is important because alterations in plant canopy cover and composition may reflect or interact with larger changes in the regional ecosystem. Processes and related systems that may be involved include the carbon cycling of the region (Rustad *et al*. 2001), regional energy balances (Chapin *et al*. 2005), and local food webs (Post and Forchhammer 2008).

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FIG. 1 The overarching project is documenting change in terrestrial ecosystems at the landscape level at Utqiaġvik and Atqasuk, Alaska. The measurements collected are done collaboratively with Steve Oberbauer at FIU and Craig Tweedie at UTEP. Top images are of Utqiaġvik. Bottom images are of Atqasuk. The center image is a map of Alaska showing the location of both sites represented as a blue (Utqiaġvik) and red (Atqasuk) star. The center images are maps showing the general location of the 1 km² grid established in the 1990s as a platform to do long-term monitoring of ecosystem change. The aerial photographs on the right are overlain by dots that represent each point of the grid. The black dots represent the location of the plots that were sampled in this study. The full grid is sampled once or twice a decade.

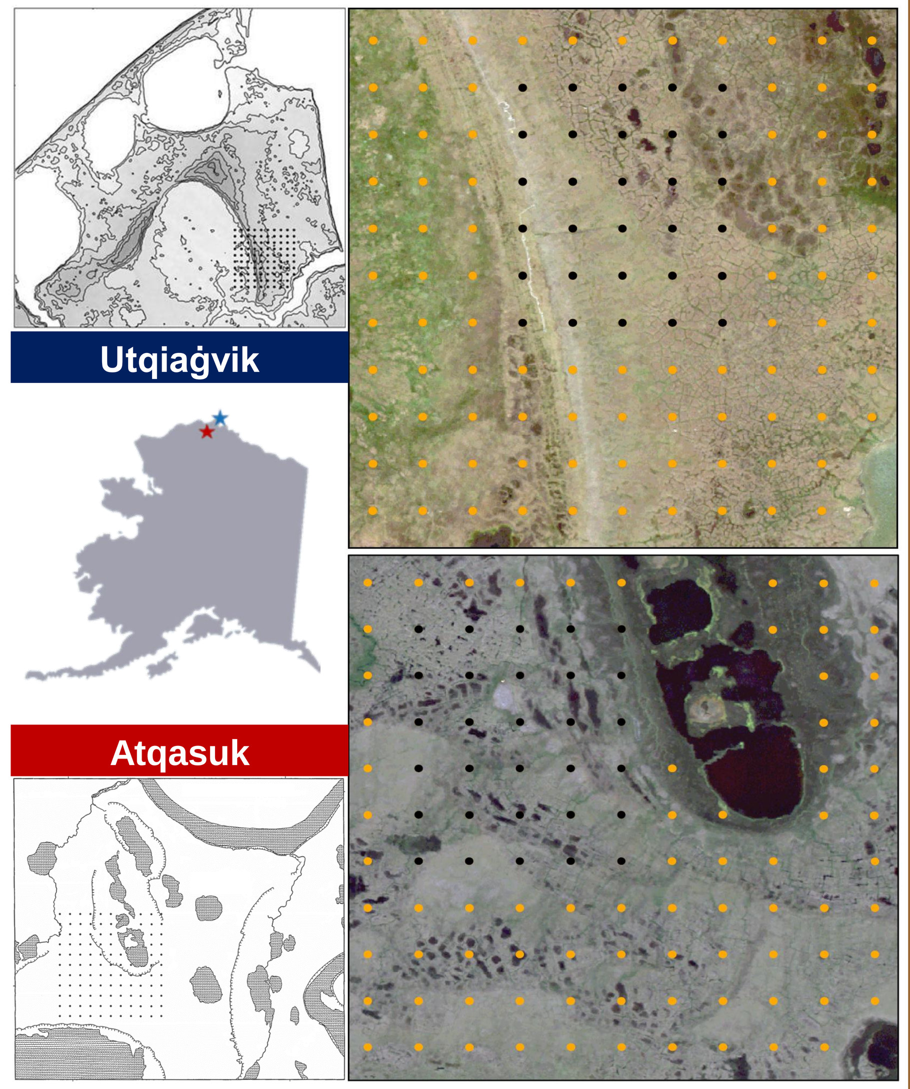

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FIG. 2 Plant cover estimates were obtained *via* a point frame method. Pictured below is the frame used at a typical plot in Atqasuk. Sampling was accomplished by placing a 100 point frame over each plot and aligning coordinates with permanently placed markers. Species were identified down to the lowest possible resolution, typically genus or species level. All plant species hits were recorded between the top of the plant canopy and the ground. All sampling was done within a two week window across years (for each plot) to minimize differences in phenological development between samplings.

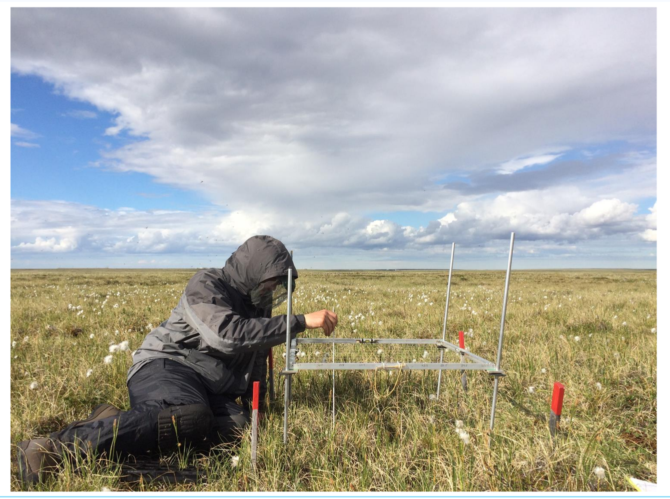


Table 1. Table illustrating linear mixed model marginal r² values between functional groups and abiotic variables bold, italicized font with an "*" represents significant values. A double "**" represents the highest marginal r². In Atqasuk, all functional groups were significantly related to year. Evergreen shrub, graminoid, and standing dead height were significantly correlated to soil temperature metrics. In Utqiaġvik, only graminoids and standing dead were correlated with years. Forb and graminoid height were correlated with air temperature metrics, and graminoid height correlated with average soil moisture.

Atqasuk

Abiotic and Biotic Factors	DSHR	ESHR	FORB	GRAM	SDEA
Number of Years (YEAR)	0.11**	0.04**	0.19*	0.21**	0.10**
Avg Air Temperature (ATEM)	0.02	0.01	0.02	0.04	0.00
Max Air Temperature (ATEM)	0.03	0.02*	0.03	0.09*	0.01
Avg Soil Temperature (STEM)	0.00	0.04**	0.02	0.03*	0.02*
Max Soil Temperature (STEM)	0.00	0.03*	0.01	0.02*	0.02*
Degree Day Sums (DDSU)	0.01	0.01	0.00	0.01	0.00
Avg Thaw Depth (THAW)	0.02	0.00	0.02	0.02	0.02
Avg Soil Moisture (SVWC)	0.00	0.00	0.00	0.01*	0.00
Sum Precipitation (PREC)	0.00	0.00	0.02	0.00	0.00

	H	p	r²	p	n
DSHR	18.48	(0.02)	0.11	<0.01	19
ESHR	22.40	<0.01	0.04	<0.01	21
FORB	30.76	<0.01	0.19	<0.01	15
GRAM	67.38	<0.01	0.21	<0.01	30
SDEA	34.39	<0.01	0.10	<0.01	30

Utqiaġvik

Abiotic and Biotic Factors	DSHR	ESHR	FORB	GRAM	SDEA
Number of Years (YEAR)	0.06	-	0.04	0.21**	0.11**
Avg Air Temperature (ATEM)	0.04	-	0.05	0.14*	0.02
Max Air Temperature (ATEM)	0.03	-	0.05**	0.14*	0.02
Avg Soil Temperature (STEM)	0.01	-	0.00	0.00	0.00
Max Soil Temperature (STEM)	0.01	-	0.00	0.00	0.00
Degree Day Sums (DDSU)	0.02	-	0.03*	0.09	0.01
Avg Thaw Depth (THAW)	0.00	-	0.02	0.00	0.01
Avg Soil Moisture (SVWC)	0.00	-	0.01	0.01*	0.00
Sum Precipitation (PREC)	0.00	-	0.00	0.00	0.00

	H	p	r²	p	n
DSHR	4.67	(0.79)	-	-	10
FORB	12.86	(0.12)	-	-	22
GRAM	73.34	<0.01	0.21	<0.01	30
SDEA	49.02	<0.01	0.11	<0.01	30

Atqasuk

Functional Groups	DSHR	ESHR	FORB	GRAM	BRYO	LICH	SDEA	LITT	H	p
Deciduous Shrubs (DSHR)	1115.69*	1289.13*	1291.40	1295.75	1289.64*	1291.99	1279.66	1283.77*	3.42	0.91
Evergreen Shrubs (ESHR)		1177.15*	1428.47	1399.66*	1430.56	1425.56*	1401.14*	1413.40*	7.04	0.53
Forbs (FORB)			640.50*	809.38*	803.46	799.53	817.23	813.16*	1.63	0.99
Graminoids (GRAM)				2099.56*	2783.60	2783.58*	2702.67*	2781.65*	92.94	<0.01
Bryophytes (BRYO)					1560.26*	2339.19*	2340.74	2202.97	28.87	<0.01
Lichens (LICH)						1101.67*	1213.28*	1184.22*	15.92	0.04
Standing Dead (SDEA)							1768.22*	2529.81*	80.51	<0.01
Litter (LITT)								1710.21*	61.15	<0.01

Abiotic Factors	DSHR	ESHR	FORB	GRAM	BRYO	LICH	SDEA	LITT
Number of Years (YEAR)	1307.38	1548.36	821.69	3137.63*	2867.38*	1711.67**	3395.26*	3094.43*
Avg Air Temperature (ATEM)	1290.56	1427.25	814.55	2780.29	2335.97	1253.52	2639.11	2780.00
Max Air Temperature (ATEM)	1290.33	1427.27	815.07	2783.13	2337.84	1253.05	2640.13	2779.09
Avg Soil Temperature (STEM)	1187.05	1255.02**	729.00*	2457.73*	2124.80**	1091.96	2356.87	2564.34
Max Soil Temperature (STEM)	1185.33	1256.58	731.82	2476.90*	2126.67	1091.70	2355.99	2559.15*
Degree Day Sums (DDSU)	1288.37	1521.93	814.53	2781.89	2823.15	1253.54	2640.18	2779.52
Avg Thaw Depth (THAW)	1151.65	1284.80	731.56	2454.94**	2095.04	1132.08	2308.21**	2406.98**
Avg Soil Moisture (SVWC)	1287.91*	1410.39*	816.55	2782.32*	2337.58	1239.66*	2638.66*	2764.79*
Sum Precipitation (PREC)	1289.98	1426.88	813.65	2782.81	2333.34*	1253.54	2638.71	2779.75

Utqiaġvik

Functional Groups	DSHR	ESHR	FORB	GRAM	BRYO	LICH	SDEA	LITT	H	P
Deciduous Shrubs (DSHR)	587.31*	-	707.17*	700.61*	712.58	712.22	705.05*	699.08*	1.40	0.99
Evergreen Shrubs (ESHR)		-	-	-	-	-	-	-	-	-
Forbs (FORB)			2547.53*	1534.38	1561.56*	1562.80*	1555.24*	1545.24*	7.92	0.44
Graminoids (GRAM)				1956.39*	2719.54	2719.76*	2720.71*	2674.40*	62.89	<0.01
Bryophytes (BRYO)					1764.51	2984.83*	2984.64	2428.41*	29.43	<0.01
Lichens (LICH)						994.11*	1198.57	1161.26*	3.61	0.89
Standing Dead (SDEA)							1640.31*	2536.32*	97.29	<0.01
Litter (LITT)								1749.08*	50.74	<0.01

Abiotic Factors	DSHR	ESHR	FORB	GRAM	BRYO	LICH	SDEA	LITT
Number of Years (YEAR)	723.59	-	1690.00	3335.36*	3189.82*	1348.97	3262.72*	3552.01*
Avg Air Temperature (ATEM)	711.90	-	1559.81	2715.02	2976.97	1203.13	2593.74	3044.06
Max Air Temperature (ATEM)	711.96	-	1559.39	2716.34	2974.25	1203.31	2592.37	3043.32
Avg Soil Temperature (STEM)	632.87*	-	1338.27*	2444.93	2619.35*	1080.46	2337.83	2725.76*
Max Soil Temperature (STEM)	633.89	-	1328.96**	2449.28	2615.80**	1080.26	2339.23	2723.60**
Degree Day Sums (DDSU)	711.81	-	1560.71	2715.00	2974.19	1203.72	2592.24	3044.92
Avg Thaw Depth (THAW)	711.13	-	1533.52*	2719.55	2972.10*	1204.19	2585.64**	3031.75*
Avg Soil Moisture (SVWC)	711.79	-	1564.06	2720.51	2983.82	1203.70	2576.61*	3044.87*
Sum Precipitation (PREC)	711.47	-	1561.64	2717.02	2976.08	1202.87	2593.60	3046.02

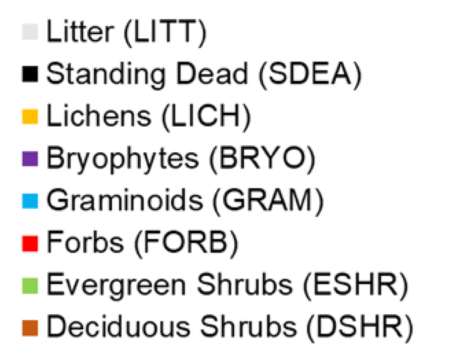
Table 2. Table illustrating functional group relationships between both biotic variables (growth form) and abiotic variables (environmental factors). Values shown on the left are Widely Applicable Information Criterion (WAIC) from a Bayesian Poisson regression and results from the Kruskal-Wallis test with year treated as factor on the right. Values with a "*" represent models which had upper and lower 95% credible intervals not overlapping zero. A double "**" indicates the lowest WAIC value for a broad functional group.

In Atqasuk there are credible regression models between evergreen shrub cover and deciduous shrub cover, bryophyte cover and deciduous shrub cover, graminoid and evergreen shrub cover, graminoid and forb cover, bryophyte and lichen cover, graminoid and lichen cover, evergreen and lichen cover, standing dead with evergreen cover, graminoid and lichen cover, and all cover relating to litter.

In Utqiaġvik there are credible regression models between forb cover and deciduous shrub cover, graminoid cover and deciduous shrub cover, bryophyte cover and forb cover, bryophyte cover and lichen cover, lichen cover, and forb cover, lichen cover and graminoid cover, standing dead with, forb, graminoid, and deciduous shrub cover, and all cover relating to litter. These relationships suggest that the drivers influencing increasing cover change may affect different growth forms similarly.

The relatively most parsimonious models between cover and abiotic variables differed slightly between sites. Overall, soil temperature and average soil moisture appear to have more credible relationships to cover values than the other variables. Notably, in Atqasuk precipitation becomes a credible factor when considering bryophyte cover. There were no functional groups in Utqiaġvik that appeared to have a credible model when regressed with precipitation.

Kruskal-Wallis test indicates there are differences in mean cover values over years for graminoids, bryophytes, lichens, standing dead, and litter in Atqasuk and graminoids, bryophytes, standing dead, and litter over years in Utqiaġvik.



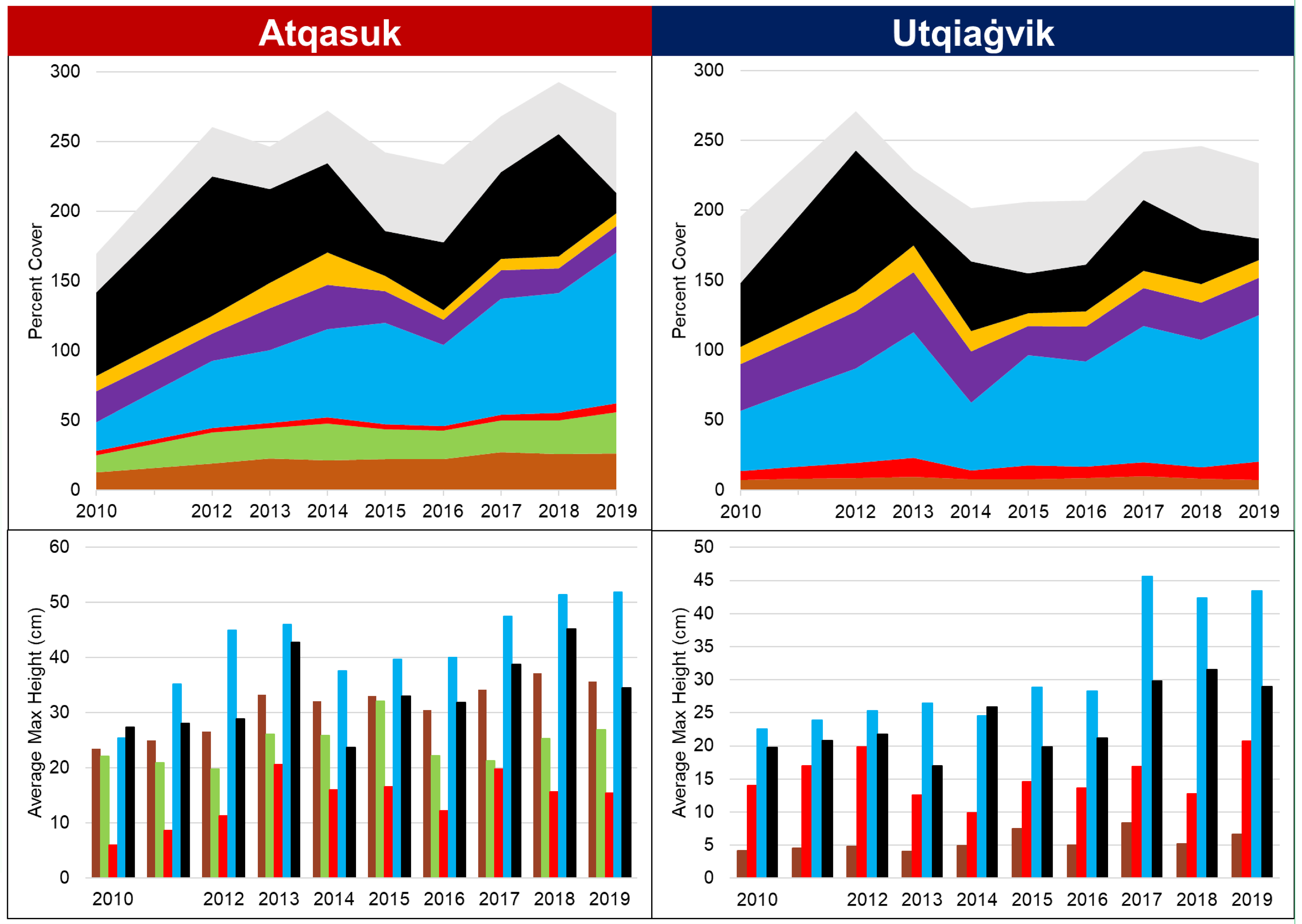


FIG. 3 Percent cover (above) and average maximum height of the main growth from types through time in both Atqasuk and Utqiaġvik. Vegetation was not sampled in 2011 (the 2011 value is the average of the 2010 and 2012 value). Cover values reflect the number of live plants hits (FIG. 2) except for the standing dead (SDEA) and litter (LITT). There were major differences in cover between years. Cover was initially higher in Utqiaġvik largely due to the increased quantities of graminoid tissue. Atqasuk has a higher abundance of shrubs and overall more live vascular plants relative to Utqiaġvik.