3.2 Vegetation Dynamics Working Group

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3.2.1 Overview

Vegetation dynamics is an umbrella theme that encompasses vegetation structure, function, processes and dynamics, and that includes projects falling under all six ABoVE Tier 2 Science Questions. Vegetation dynamics help control ecosystem services (3.1), integrate past and feedback to future disturbance (3.2), indicate and help control permafrost (3.3), influence hydrology (3.4), determine flora and fauna abundance (3.5), and store and cycle carbon and other elements (3.6). Research on vegetation dynamics links field observation, remote sensing analyses and ecosystem model development. The cross-cutting nature of the vegetation dynamics theme highlights the interconnectedness of the overall ABoVE research effort, as well the diversity of data that will be collected and analyzed.

The activities in the vegetation group are loosely categorized into five areas (Table 1): 1) research focused on specific biological processes such as plant physiology, soil biogeochemistry and nutrient cycling, and the spread of insects and disease; 2) research on the expansion of shrubs and taller stature vegetation at tree line and into tundra; 3) research on recent changes in boreal forest vegetation, including stress, dieback and expansion; 4) research on vegetation recovery and succession following disturbance; and 5) research to understand or map the spatial distribution of vegetation attributes such as canopy cover and plant functional type.

This document organizes the vegetation dynamics research in ABoVE into efforts that emphasize (Section 2) the collection of new field datasets, (Section 3) the collection and/or analysis of remote sensing data, and (Section 4) the development and testing of models. This document also identifies (Section 5) synergies with other working groups, and (Section 6) research gaps not covered by the current suite of funded projects. Each section includes a synopsis of the overall activities of the current working group members, and identifies needs and recommended next steps.

Table 1. Common Vegetation Dynamics science themes and corresponding ABoVE Tier 2 Science Objective(s).

Common science themes	Group(s)	Most relevant ABoVE Tier 2 science objectives (SO; Tab 3.1)
1) Mechanistic controls on plant physiology and soil biogeochemistry, including changes in phenology, growing season length, permafrost and hydrologic conditions, and drought stress	Eitel, Gamon, Kremers/ Rocha, Morton, Woodcock	How climate change and disturbances interact with communities and processes to alter carbon biogeochemistry [SO6]
2) Shifting patterns of tundra vegetation density, with an emphasis on greening, shrub encroachment or treeline dynamics.	Chopping, Frost, Goetz, Greaves/ Vierling, Kremers/ Rocha, Prugh, Ranson, Vierling,	Causes of greening and browning trends [SO5]
3) Shifting patterns of boreal forest vegetation density and extent, with an emphasis on greening and browning	Cook, Eitel, Goetz, Goulden, Ranson, Woodcock	Causes of greening and browning trends [SO5], and How vegetation attributes interact, and respond and

trends, fire and insect mortality.		feedback to disturbance [SO3]
4) Relationships between disturbance and recovery, including effects on soil properties and vegetation composition, structure, and function.	Cook, Frost, Goulden, Morton, Rocha (affiliated), Rogers	How vegetation attributes interact, and respond and feedback to disturbance [SO3]
5) Distribution of vegetation structure and type.	Cook, Eitel, French (affiliated), Frost, Goetz, Greaves/ Vierling, Morton, Ranson, Vierling, Walker, Woodcock	Important for all Tier 2 questions [including SO3, SO5, SO6]

3.2.2 Field Research on Vegetation Dynamics

3.2.2 a. Synopsis: Roughly half of the research groups are planning field work. These field efforts can be organized around three axes: 1) type of measurement, 2) sampling design, and 3) expected location(s). The main types of measurements include: a) plant physiology or stress using techniques such as micrometeorological gas exchange or foliar fluorescence, b) plant community composition, demography, recruitment, and mortality, c) meteorology, hydrology, snow and permafrost, d) vegetation structure such as height and LAI, e) biogeochemistry and carbon pools and fluxes, f) ecological legacies and history, including tree rings, permanent sample plots (PSPs), fire history and biogeochemical pool ages, and g) local remote sensing such as passive reflectance or LiDAR. Common experimental or sampling designs include: a) climate gradients (climosequences), b) fire recovery gradients (chronosequences), c) drainage gradients (toposequences), d) focused sampling at key locations such as ecotones, e) focused sampling of key periods such as immediately after a fire, f) recent change gradients, such as a range of recent greening, g) systematic wall-to-wall or long transect sampling (most relevant to remote sensing), h) a nested multi-scale sampling approach, where intensive core sites are combined with a more extensive network of auxiliary sites, i) disturbance severity gradient.

Table 2. Planned field work to address vegetation dynamics.

Main science theme(s)	Vegetation attributes(s) and approach(s)	Expected study location/region	Sampling design	PI
1) Physiology, biogeochemistry		Existing flux towers		Gamon
2) Tundra greening		Treeline along Dalton Hwy, Yellowknife		Eitel
2) Tundra greening		AK tundra		Vierling, Greaves
2) Tundra greening	Field data from Toolik LTER manipulation plots and eddy covariance	North Slope of Alaska	Remote Sensing (MODIS), modeling, eddy covariance, data assimilation	Kremers/ Rocha
2) Tundra greening	Plant community composition, permanent sample plots, vegetation structure and cover	YK Delta	Toposequences, recent change gradients	Frost
2) Tundra greening	Vegetation structure, composition, spectral properties	Dalton Highway, Prudhoe Bay, Western Alaska Arctic transects	Large collection of historical plots	Walker (affiliated)
2) Tundra greening, 3) Boreal forest greening/ browning	No new field work in tundra; Tree ring measurements in boreal stands, isotope analyses in some permanent sample plots (PSPs).	Denali park and Healy area; Canadian boreal forest and aspen parkland	Revisiting existing PSPs that include climate & fire recovery gradients	Goetz

		(CIPHA sites)		
3) Boreal forest greening/ browning, 4) Disturbance and recovery	Plant physiology, stress, community composition, meteorology, structure, local remote sensing. Using biometry, micrometeorology, reflectance	Fairbanks	Chronosequence, browning gradient, nested with intensive and extensive sites	Goulden
3) Boreal forest greening/ browning, 4) Disturbance and recovery, 5) Structure and distribution	USFS AIRIS protocols (location, landscape position, stand condition, tree data, shrub and ground cover, thaw depth)	Tanana Valley, AK	Grid of 8 ha plots spaced 40 km (n=84)	Cook
4) Disturbance and recovery	Plant community composition; vegetation structure; biogeochemistry and carbon pools and fluxes; ecological legacies and history	Central Saskatchewan	Gradients of pre-fire species (black spruce vs. jack pine) and stand age	Rogers
4) Disturbance and recovery	C,N,P cycling, soil and atmospheric meteorology & Eddy covariance fluxes along a burn severity gradient	Anaktuvuk River Fire North Slope, AK.	Recovery of tundra 1-20 years across a burn severity gradient	Rocha (affiliated)
4) Disturbance and recovery, 5) Structure and distribution	AK FIA (location, landscape position, stand condition, tree data, vegetation profile, downed wood, ground cover, thaw depth, soil properties)	Tanana Valley and Kenai Penninsula, AK	Grid of USFS FIA plots throughout Tanana Valley (n≈1000 by 2018)	Morton

3.2.2 b. Next steps and planning

Identify, plan for core sites and common sites - facilitate communication among groups working in common areas. The use of core sites can both enhance scientific return through the co-location of broader suites of measurements, and increase overall efficiency by resource sharing. In addition, core sites can serve as logistical hubs and provide additional centralized science support, including airborne remote sensing datasets and field technician support. The group recognizes that sharing of core study plots and transects will not work for all projects, and it is important that groups are ultimately allowed to select the sites that will best allow them to achieve their individual research goals. Nonetheless, there may be cases where groups have flexibility in site selection, and in these cases the value of co-locating a diverse suite of studies should be considered. Possible core sites may include a range of vegetation types and successional stages along environmental gradients of climate, topography, soils and hydrology.

The identification and selection of these plots and sites is a high priority since it informs the airborne data acquisitions (see sections on core variables and airborne science). The location of core sites, which is ongoing, is being made with experimental design in mind: i.e., including locations that represent large gradients and may help to reveal meaningful trends and tests of specific hypotheses (e.g. related to "greening" and "browning" trends). This selection can be facilitated by analyzing existing RS products to identify locations along environmental and vegetation gradients such as NPP, LAI and vegetation cover, and locations of particular sensitivity or uncertainty in models.

Circulate protocols for frequently-used measurements. Research groups often use broadly similar field sampling procedures that differ only in a few specific details. Some groups may be adaptable about these details, and can adopt a modified protocol that improves cross-group comparisons and increases effective sample sizes. Possible areas for standardized sampling includes vegetation structure, biomass and production, species composition, and/or soil physical or biogeochemical attributes. For example, forest inventory protocols used by the USFS FIA and Canada's National Forest , and tundra shrub inventory protocol used by Duchesne et al. (2015). It may be possible for other groups to adopt these protocols with no deleterious impact to their own project, thereby increasing measurement consistency, sample size and sample coverage. The vegetation group recommends the creation of a wiki or other approach to facilitate the easy exchange of measurement protocols, with the ultimate goal of providing standardized protocols and best practices in field data collection.

Circulate wish lists for additional measurements or sample collection. Some observations or samples are easily and rapidly collected once at a site; the main cost of the measurement is the time needed to travel to the field site. These measurements or sample collections could be piggybacked onto other visits with little incremental effort or time. The vegetation group recommends the creation of a wiki or other approach to facilitate the easy request of supplemental measurements or sample collections.

Accurately locate all plots. Easy access to survey-grade GPS and associated training for GPS operation will help to both validate DEMs and geolocate measurement plots for comparison with remotely-sensed observations. The vegetation group recommends that each project collect very high accuracy GPS data (<1m) at all field sites and field plots. This information will require survey-grade GPS, which many groups do not possess; the vegetation group recommends that the ABoVE project obtains and manages at least two high resolution GPS units and provides training opportunities for their operation. The vegetation group also recommends that these geolocated data be available to view on a common map through the ABoVE Science Cloud.

3.2.3 Remote Sensing Research on Vegetation Dynamics

3a. Synopsis.

Remotely sensed data and their derivative geospatial products are central to nearly all of the projects that make up the Vegetation Dynamics group, and represent a common thread throughout the entire ABoVE project. Specific remote sensing research in the Vegetation Dynamics group will support efforts to scale key vegetation processes across time and space. These scaling efforts are critical to the ABoVE project because field experiments are limited in spatial and temporal representativeness. As a result, the remotely sensed data and products serve as a bridge to link field-based studies with modeling studies (discussed in more detail below). While the remote sensing research to be conducted by the Vegetation Dynamics group will be broad in scope, the main themes of this work include: 1) understanding how plant physiological signals can be detected and scaled across time and space, 2) understanding the dynamics of vegetation structure and function through combined passive and active remote sensing, and 3) understanding how radiometric variability unique to arctic and boreal regions (e.g. low sun angles) affect the study of vegetation dynamics across broad scales.

Table 3. Planned remote sensing work to address vegetation dynamics.

Main science theme(s)	Vegetation attributes	Instrument(s)	Expected study location/region	Sampling design	PI
1) Physiology, biogeochemistry	Stress	MODIS, Field Spec	Existing flux towers		Gamon
2) Tundra greening	Plant establishment	Airborne and terrestrial scanning lidar, Landsat	Treeline along Dalton Hwy, Yellowknife		Eitel
2) Tundra greening	Shrub abundance	Commercial High-Res (and possibly historical aerial photography and Gambit/Corona imagery)	Alaskan and Canadian erect dwarf-shrub and low-shrub Arctic tundra zones		Chopping
2) Tundra greening	Community composition	Commercial high-res and historical aerial photography, lidar, Landsat, MODIS	YK Delta	Nested multi-scale sampling	Frost
2) Tundra greening, 3) Boreal forest greening/browning	Shrub & lichen cover extent and change; Boreal tree mortality	Commercial High-Res, Landsat & MODIS, Aerial photos	Alaskan and Canadian erect dwarf-shrub and low-shrub zones, Southern boreal of Alaska & western Canada	Systematic wall to wall mapping & time series analyses of the study regions.	Goetz
3) Boreal forest greening/brownin 4) Disturbance and	Structure (LAI, canopy ht, fraction	Landsat	Interior Alaska, Manitoba	Chronosequence, browning gradient	Goulden

recovery	deciduous)				
4) Disturbance and recovery	Species, carbon pools	MODIS, Landsat	Boreal forest	Chronosequence	Rogers
3) Boreal forest greening/browning 4) Disturbance and recovery, 5) Structure and distribution	3D structure, topography from lidar and stereoimages; land cover, vegetation, pigments from lidar, VNIR imaging, moisture from thermal	G-LiHT (2014); stereo aerial photographs from 1982-83 and 2012-14; Landsat TM, ETM+, OLI	Tanana Valley, AK	Coincident airborne and satellite data collected over AIRIS photo and ground plots across entire Tanana Valley (systematic grid spaced 40 km apart)	Cook
4) Disturbance and recovery, 5) Structure and distribution	3D structure, topography from lidar; land cover, vegetation, pigments from lidar, VNIR imaging; moisture from thermal	G-LiHT (2014); Landsat TM, ETM+, OLI	Tanana Valley and Kenai Penninsula, AK	Coincident USFS FIA, DoD, and NPS inventory plots and G-LiHT transects every 9 km across the entire Tanana Valley.	Morton
3) Boreal forest greening/browning 5) Structure and distribution		Landsat, including side laps	Entire domain		Woodcoc k

3b. Next steps and planning

Compile a list of best practices of satellite data product use. While all members of the ABoVE science team have some expertise with remote sensing datasets, the level of expertise varies within the group. Only a subset of the team has true "world class" expertise on the methodological details of remote sensing, as well as inside knowledge of the methodological advances and data availability expected over the next few years. It is important that the broader ABoVE science team learns and benefits from these experts. One possible strategy to rapidly spread this knowledge is the creation of a bibliography describing recent advances and best practices in products and their usage, such as a discussion of the advances with MODIS Collection 6. Further progress will be facilitated by sharing data and products on the ABoVE Science Cloud (ASC). Efforts to rapidly share both derived datasets and processing code promise to raise the overall quality of remote sensing science across the science team. Mini-workshops and webinars are helpful for the Science Team to best utilize the ASC.

Establish a common set of vegetation classifications. A number of groups will either further develop or use maps of vegetation classification, and the vegetation group feels that additional efforts are needed to homogenize the specific classification categories used. Existing vegetation maps often differ in the number, type or definition of classifications; these differences can create step changes, both spatially or over time, and necessitate difficult and often uncertain efforts to cross-walk legends. The vegetation group recommends the development of a standardized hierarchical legend for mapping and site characterization (e.g. Walker-01), and to support field site selection and sampling locations (i.e. actual vegetation, including functional groups of e.g. lichen, graminoids, shrub, tree).

Plan for airborne campaigns. The vegetation group enthusiastically endorses the planning for one or more airborne remote sensing campaigns, and hopes to contribute to a campaign that is very explicitly targeted at answering one or more specific science questions and is closely coordinated with any relevant field based observations. The previous sections of this document describe the key questions addressed by the vegetation group, along with the measurements planned and available sampling/experimental designs. The airborne science WG has a similar and parallel organization, with data acquisitions that overlap spatially and temporally with the sampling and experimental designs used by the field groups, instrument packages that can be related to the in-situ observations, and much broader coverage that allows the in-situ measurements to be placed in the broader context and be used in spatial scaling. Cutting-edge, experimental airborne remote sensing technology (e.g. multi-wavelength LiDAR) may afford new remote sensing research opportunities.

Develop a strategy for opportunistic data collection. ABoVE has been scoped as a 10-year experiment, and it is almost certain that parts of the study region will experience unexpected or unusual extreme events during the project. Potential events include natural disasters (fire, thermokarst, insect outbreak, severe drought), as well as areas of extreme model/observational disagreement. It is not possible to specifically plan or schedule for these events, but it is nonetheless possible to put in place a contingency strategy for targeted observations that focus on sampling unusual or anomalous events, locations, or periods using a combination of airborne, satellite, field and modeling efforts. A proposal to NASA's Rapid Response and Novel Research in Earth Science announcements is one way to take advantage of these opportunistic events.

Develop a strategy to leverage and further improve upon the PGC fine-scale DEM. The Vegetation Dynamics group could benefit greatly from the fine-scale (i.e. 2-10m resolution) DEM in production by the PGC. This DEM should provide a baseline dataset against which to compare future observations collected when studying the various science objectives mentioned in the previous sections of this document. The Vegetation Dynamics group recommends that a coordinated strategy be developed by the ABoVE science team to add value to this DEM through validation and error assessment. In addition, efforts to differentiate the DEM into ground (i.e. digital terrain model, DTM) and canopy (i.e. canopy height model, CHM) components could be of great use to many studies (both among the vegetation group, as well as others) due to the fine grain and broad extent of these data.

3.2.4 Modeling Research on Vegetation Structure, Function, Processes & Dynamics

3.2.4a. Synopsis.

Several current and yet-to-be-funded modeling efforts will crosscut many of the ABoVE science working groups. Modeling efforts in the Vegetation Dynamics working group fall into three thematic areas: 1) spatial modeling and scaling of vegetation dynamics from local/landscape scales (~10^0-10^5 m^2) to regional/domain-wide scales ((~10^5 m^2 and up), 2) temporal modeling and scaling of vegetation dynamics from short, intensively measured time scales (~minutes to weeks) to longer (seasons to decades), and 3) ecophysiological modeling from the sub-cellular to the stand level. Modeling efforts will include characterization of both episodic (e.g. disturbance-related) and continuous (e.g. phenology-related) events to capture vegetation dynamics through space and time. Comparisons between models and remote-sensing products allow detail models to be tested, and likewise, comparisons between ecosystems properties derived from models and analogous properties derived from remotely sensed vegetation provide insight into our understanding of ecosystem functioning.

Table 4. Modeling efforts to be conducted in studying Vegetation Dynamics science themes, with location and specifically funded projects listed.

Main science theme(s)	**Modeling effort**	**Expected study location/region**	**PI**
2) Tundra greening	Coupled radiative transfer-micrometeorological-ecophysiological modeling to describe treeline regeneration and stress dynamics	Forest-tundra ecotone sites	Eitel
2) Tundra greening	Scaling of ecophysiological treeline modeling to ABoVE-wide maps of treeline structure	Forest-tundra ecotone	Eitel
2) Tundra greening	Landscape scale retrievals of shrub biomass and leaf area via LiDAR data	Tundra (AK)	Vierling
2) Tundra greening	Tundra summertime diurnal CO_2 flux	Tundra (AK)	Vierling
2) Tundra greening, 3) Boreal forest browning	Forest productivity, demographics (mortality), and range shifts	Boreal forest	Goetz
4) Disturbance and recovery	Post-fire vegetation succession using UVAFME gap model	Boreal forest	Rogers

3.2.4b. Next steps and planning

Coordination between groups interested in modeling, including those in the modeling WG. Several areas of increased coordination and discussion between groups using models would be useful. A potential benefit to having shared study sites (core sites or otherwise) is to facilitate nested sampling designs in support of spatial modeling; discussions of nested sampling designs to support modeling is needed. Discussion of how model errors and other uncertainties may be constrained through coordinated experimental designs may be useful. The modeling WG has a strong interest in using intercomparisons and knowledge gaps from large-scale Terrestrial Biosphere Models (TBMs) to inform other WGs on data collection/processing. One important link is the use of the datasets and regional models produced by the Vegetation Dynamics WG as benchmarks for model intercomparisons.

In a more general sense, efforts to increase the intellectual exchange across all groups is important, as has been emphasized at each ABoVE Science Team meeting. There are many cases where modeling and conceptual efforts from projects can inform one another and provide unique learning opportunities to advance model skill and reorient field data collection efforts to better inform modeling (see Modeling WG section).

Coordination between modeling and non-modeling groups. Increased coordination between modeling and observational groups is strongly encouraged. This interaction should be viewed as fully bi-directional; model output can be used to help define field or aircraft sampling designs and suites of observations, and field or aircraft observations can be used to test and improve models. Efforts to advance these interactions, such as through science team meetings, ongoing working group interactions, and *ad hoc* meetings are strongly encouraged. For example, measurement of vegetation traits (described earlier in this WG section) is a critical link for calibration and validation of models. Many models of vegetation processes are directly relatable to field data. Detailed models informed by and tested against sparse field data can be applied at spatial scales to complement remote sensing products of vegetation attributes. A necessity of modeling is the general representation of complex field conditions. Many global models have summarized vegetation into a collections of similar species as plant functional types (PFTs) with the physiological and ecological parameters used to model a given PFT defined by a subset of point-scale observations. Increasingly, this PFT generalization is being recognized as problematic as it does not allow a robust analysis of future vegetation dynamics, and likely contributes to uncertainties in model predictions (Alton 2011; Wullschleger et al. 2015; Verheijen et al. 2015). Through the collection and standardization of key plant species characteristics (wood density, specific leaf area, leaf onset, leaf area index, etc.), it is possible to contribute to repositories such as TRY and CAVM that inform model calibration and validation. Quantification of within-PFT differences through field data and species-specific modeling is an important part of improving PFT-based vegetation models. An essential component of this nested reliability among field, modeling and remote-sensing products is the effective overlap of sites across key/core sites, as noted earlier.

3.2.5 Synergies

Many of the local or regional scale studies of vegetation structure and function provide critical calibration/validation efforts for other projects, in particular for ecosystem modeling studies. Some synergies will come from shared methods for field or remote sensing data analysis (Sections 3 & 4). Still other ideas are likely to come from extending current studies. For example, commercial high-resolution data used to generate a regional digital surface model (PI Morin) could also be used to evaluate vegetation composition, based on the multispectral information for each image tile used in the DSM product. Further synergies might be realized between different approaches to characterizing vegetation at sites, e.g., combining structural information such as plant height from lidar or crown radii from analysis of panchromatic imagery with information on vegetation type from multispectral or hyperspectral imagery. We expect additional and logical synergies with other WG activities as well, including the Disturbance, Wildlife & Ecosystem Services, Carbon Dynamics, Hydrology & Permafrost, and Modeling WGs. Many of these interactions have already been initiated.

3.2.6 Identified data and/or knowledge gaps

One data gap that will aid members of this WG is a consistent vegetation type map for the ABoVE domain. Different groups have different needs, but several projects would benefit e.g. from access to a gridded map of forest species composition. For example, some Fire Disturbance WG projects will be merging the FCCS fuel type map for AK (30m) with a kNN species map of Canada (250 m).

Another potentially important data gap is the spatial history of non-fire (both biotic and abiotic) disturbances. Such information is likely to be important in determining the causes of recent “browning” episodes, especially in forested regions. Examples include spruce beetle (SW Yukon), willow leaf miner and aspen serpentine leaf miner (widespread, multi-year outbeaks in deciduous forest and shrublands across Alaska and NW Canada), as well as recent, northward range expansions of spruce budworm (Mackenzie valley north to near Inuvik), forest tent caterpillar (aspen in SW NWT) and mountain pine beetle (lodgepole pine in northern BC and Alberta). To meet this information need, it would be useful to conduct a review of insect & disease survey records including collation of historical records in map form across the ABoVE study domain. In addition, direct human disturbance, extreme climate events, and physical changes (e.g. landslides from permafrost thawing) are potentially important disturbances to better understand in the context of ABoVE.

Homogenizing historical and near-real time climate observations across space and time: e.g., jurisdictions and/or climate observation networks with different measurement protocols, notably snow fall in Alaska versus Canada, while documenting changes in methods, quality and coverage over time is an additional priority data need that would also serve various other ABoVE WGs and their stakeholders.

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