



Aspen Phenology Monitoring Protocol for the Central Alaska Network

*Plot establishment, field measurements, and data
management*

Natural Resource Report NPS/CAKN/NRR—2019/2014



ON THE COVER

Images of aspen marked for monitoring, in flower, fully leafed out, and in fall colors.

NPS/E. FLEUR NICKLEN

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October 2019

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

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Please cite this publication as:

Roland, C. and F. Nicklen. 2019. Aspen phenology monitoring protocol for the Central Alaska Network: plot establishment, field measurements, and data management. Natural Resource Report NPS/CAKN/NRR—2019/2014. National Park Service, Fort Collins, Colorado.

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Abstract

Plant phenology can be highly responsive to temperature and climatic variations and is one of the most sensitive indicators of climate change. There is considerable evidence global climate change is advancing the timing of flowering and leaf-out and extending growing seasons of plants at northern latitudes. The Central Alaska Network began monitoring the phenology of aspens in Denali National Park and Preserve in 2005, added monitoring stations in 2008 in Yukon-Charley Rivers National Preserve and Wrangell-St. Elias National Park and Preserve, and in 2010 added a fourth monitoring location in Fairbanks, Alaska. This document describes the protocol used to establish and monitor these plots. The protocol covers plot establishment, spring and fall monitoring procedures, photo documentation of plots, and data management.

List of Terms and Acronyms

CAKN: Central Alaska Network

Catkins: A pendulous, apetalous flowering spike composed of flowers of a single sex.

DBH: Diameter at breast height (1.37 m above ground).

Green-up: The process of leaf buds bursting, then unfurling, and expanding to full leave size.

Phenology: The scientific study of periodic biological phenomena, such as flowering, breeding, and migration, in relation to climatic conditions.

Phenophase: An observable stage or phase in the annual life cycle of a plant or animal that can be defined by a start and end point.

Senescence: Aging; in this protocol: aging or yellowing of leaves.

Background and Objectives

Importance of Phenology Monitoring

Phenology, the timing of recurring biological events such as flowering and leaf-out of plants, can be highly responsive to temperature and climatic variations and is one of the most sensitive indicators of climate change. There is considerable evidence global climate change is advancing the timing of flowering and leaf-out and extending growing seasons of plants at northern latitudes. For example, warming in the northern hemisphere between 1955 and 2002 has advanced the first leaf out date by 1.2 days per decade (Schwartz et al. 2006). Advanced springtime plant phenology and lengthened growing seasons have important consequences for plant growth and reproduction (Inouye 2008) and plant-animal interactions like herbivory (Langvatn et al. 1996, Pettoirelli et al. 2007) and pollination (Price and Waser 1998, Cleland et al. 2007, Memmott et al. 2007). Phenology influences plant fitness (Primack 1980) and as a result influences species geographic ranges, particularly at their northern limits (Chuine and Beaubien 2001). The timing of plant green-up and senescence affects carbon flux in our ecosystems (Baldocchi et al. 2001, Richardson et al. 2009), the albedo of the earth's surface (Reich et al. 2009), and terrestrial water cycling (Young-Robertson et al. 2016), each important facets of our climate. For these reasons the Central Alaska Network has identified plant phenology as a vital sign to measure.

Plant phenology is an integral part of human lives, especially in cold northern regions where the change in seasons is a dramatic event experienced by all. Monitoring the timing of leaf-out, flowering and senescence is an excellent way to involve park personnel across the interior and Arctic with monitoring initiated by the Central Alaska Network and provides an excellent educational experience to visitors.

Monitoring phenology, in concert with anticipated driving environmental covariates and subsequent analysis, can help park managers to (1) understand what environmental cues are important regulators of phenology, (2) use this knowledge to make predictions about how phenology may change given expected climate variability, and (3) detect and analyze change over time once a long record of observations have been made. Additionally, detailed measurements of the phenology of individual plants (such as what this protocol describes) can inform larger-scale remote sensing studies, serving as “ground-truthing” of remotely-sensed phenology data.

Relationship of Phenology Monitoring to Overall CAKN Vegetation Monitoring

Phenology monitoring is one component of the larger CAKN vegetation monitoring program. The primary vital sign within the Central Alaska vegetation monitoring program is the landscape-scale vegetation structure and composition monitoring program, which is executed according to a multi-stage systematic grid design over wide areas in the three Central Alaska park units (Roland et al. 2004). Work accomplished for the landscape-scale program is, of necessity, focused on elements of the vegetation with considerably less interannual variation than plant phenology. For example, the small incremental differences in tree diameters, or species composition, measured across a five year span for a given plot would, in the absence of disturbance, generally have much smaller coefficients of variation than the green-up date across the same five-year period for the plot. It is important to

acknowledge, however, that plant species whose primary perennating tissues are below ground, and as such die back each year (e.g., graminoids and many forbs) will exhibit some variation in year-to-year biomass production, based in part on annual weather conditions. Thus, in a short and cool growing season there may be (on average) less cover of some plant species than there would be in a warm or long growing season. In addition, sustained changes in growing season length over long periods of time could eventually result in changing patterns in plant species distributions that would be captured in the landscape-scale measurements. Capturing this interannual variation in phenology over the long term would thus provide important context for understanding shifting species distribution patterns that may be observed at the larger spatial scales within the network.

Aspen Phenology Monitoring in the Central Alaska Network

We began a monitoring program to track plant phenology, the timing of flowering, green-up, and foliar senescence of aspen (*Populus tremuloides*, *Salicaceae*). We chose aspen because it is sensitive to interannual variation in weather (Meier et al. 2015). It is also a widely distributed species that is monitored in other national and international phenology networks and thus our results can be examined within regional, continental and global contexts. [PlantWatch](#) is a Canadian national volunteer monitoring program that monitors aspen among other species, and The National Phenology Network is a United States phenology monitoring program that monitors aspen as one of its “calibration” species: species that have broad distributions and are ecologically and economically important (http://www.usanpn.org/?q=Populus_tremuloides). The goals of this long-term phenology monitoring are to (1) track the interannual variation in the timing of flowering, bud burst, green-up and senescence of aspen in selected, readily accessible locations, (2) detect changes in aspen phenology over time at our study sites, (3) model the environmental (climatic) drivers of variation in aspen phenology and use these models to help expand our inference spatially and temporally, (4) and finally to assess the impact of phenology and season length on aspen radial growth.

Established Monitoring Sites

In 2005, we established two aspen phenology monitoring plots in Denali National Park. The program was expanded in 2008 to include sites near Eagle on the Yukon River in eastern interior Alaska and at Copper Center in the Copper River basin in south-central Alaska. In 2010, we added a site adjacent to the Georgeson Botanical Garden on the University of Alaska, Fairbanks Campus (Figure 1). In 2012 we added a second Fairbanks plot. We established a second Copper Center plot in the fall of 2018. The Eagle plot was discontinued in 2009 when park staff became too limited to continue observations. There are weather stations within 20 km of each of these sites to which the phenology data can be correlated: Denali Park headquarters weather station, Eagle Airport weather station, Gulkana Airport weather station, and the Alaska Climate Research Center weather station on the University of Alaska Fairbanks campus.

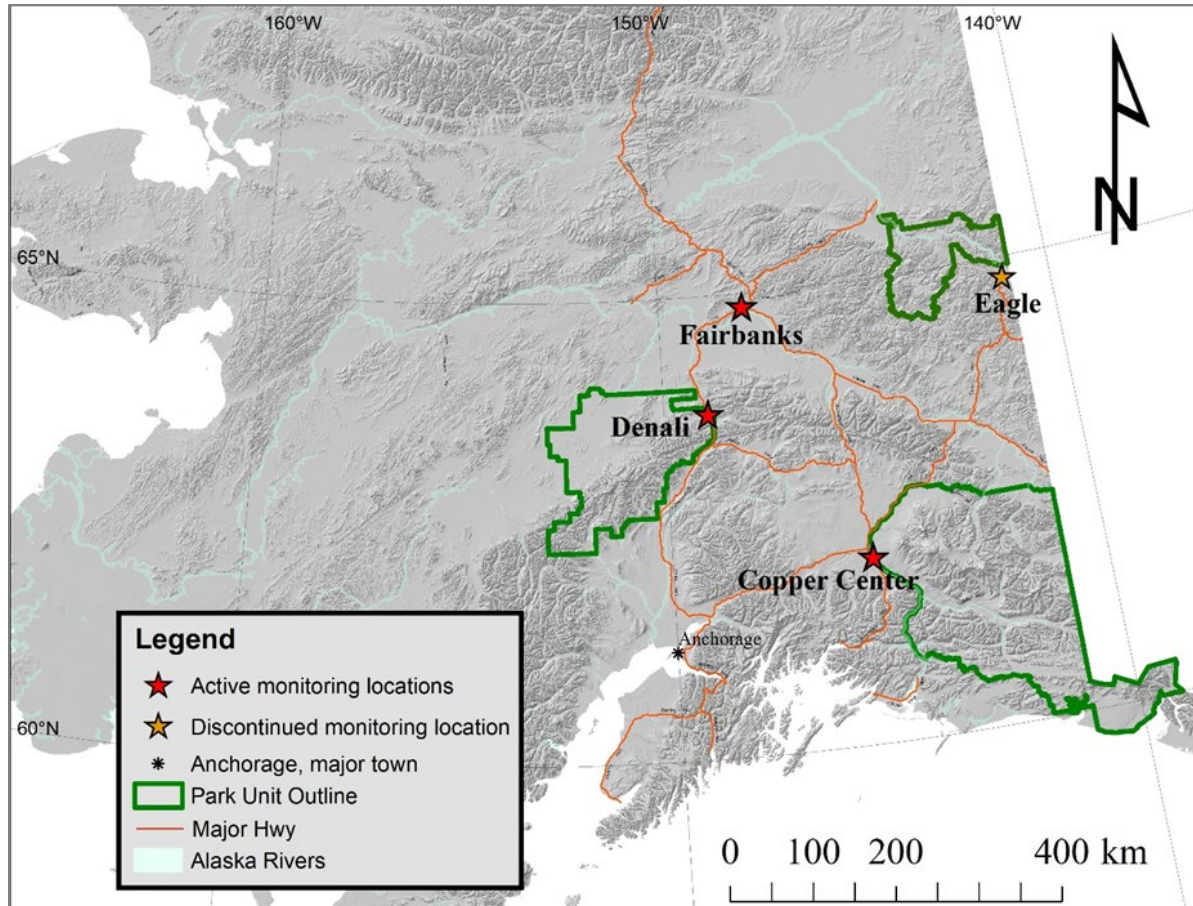


Figure 1. Map of south-central and interior Alaska showing the Central Alaska Network aspen phenology observations sites (red stars).

Choosing Monitoring Sites

Monitoring sites are selected for (1) the presence of aspen as the dominant or codominant tree species, (2) convenient access from park headquarters due to the high frequency of observations times and reliance on park staff volunteering time and (3) no to minimal human disturbance (at least 5 m of buffer from the nearest trail to a monitored tree and no obvious tree clearing within the plot). Because our sites are non-randomly selected, our frame of inference is limited to our sites; however, we expect aspen growing in interior Alaska to respond similarly to environmental driver as the trees in our study plots. Thus, models of aspen phenology developed from our observations should be applicable to aspen in other areas of interior Alaska or further afield, though validation of our model predictions from independent phenology observations outside of our plots will be needed. Ideally, each site will have two paired plots separated by at least 250 m to ensure non-clones are observed and help assess the possible influence of site conditions (sloping vs flat, early vs late succession) on aspen phenology. Each plot consists of twelve randomly chosen and marked trees within an area of about 2,500 m².

Aspen Phenology Monitoring Overview

Timing of Observations

Phenology measurements take place for about a month and a half in spring and in fall. Spring observations begin in early April, at a point early enough to capture the snow-melt date and the first date of catkin emergence. Typically April 6th is a good starting date for the spring measurements, though observers should be ready to start observations earlier if necessary. Observations end once the leaves have fully expanded on each of the monitored trees. Fall observations begin just prior to when any of the trees have started to turn yellow, typically in early to middle August (August 6th), and continue until all the leaves on each of the twelve trees are yellow, usually in mid-September. It is possible the dates of monitoring may shift as the timing of phenological events shift over time.

Overview of Observations

The observations consist of three parts: the sample event data, phenophase observations and photo documentation. From 2005 to 2011, soil temperature was also recorded along with the phenophase data (two soil temperature measurements 1.5 m from the tree base were made at each tree during each sampling event). Starting in 2012, the air and soil temperature procedure was dropped from the protocol. The soil temperature measurements were the slowest part of the monitoring process and after six years regression analysis revealed no correlation between phenology and point-in-time soil temperature. In the future using a datalogger to record continuous soil temperature and/or taking soil thaw depth in monitoring plots could be useful metrics. Recording sample event data consists of noting the following information: date, time, personnel identification, current weather and any observations about the site or recent weather events. Phenophase observations involve pinpointing the phenological state of each tree through repeated observations as described in SOPs 2 and 3. Photo documentation comprises of taking a repeat photo from one spot in the plot at least once each week of observations during critical times of phenology change as well as taking other photos of the plot important for documenting the phenological state. The photos are used as a qualitative check and calibration of observers. In the future, repeat or timelapse photos could be translated into quantitative metrics, although that is not part of this protocol. The observations are simple and can be performed by anyone with about a half hour of training. The observations themselves take 10 to 30 minutes per plot.

Personnel Responsibilities, Training, and Time

This monitoring protocol is reliant on a variety of network staff, park staff, seasonal employees, and volunteers to accomplish the annual phenology observations. The hierarchy of personnel responsibilities is as follows: the network phenology monitoring PI provides overall program coordination and leads data analysis and reporting. The network botanist as well as the network phenology PI conduct observations when needed, but are primarily responsible for recruiting and training observers and ensuring observers have the necessary materials to conduct observations. Field observations are primarily conducted by network seasonal employees, interns (e.g., from the Student Conservation Association), and other park staff. The network botanists and biological science technicians are responsible for data QA/QC, data entry, and data reporting as needed.

Quality observations in the field are achieved in the following ways. First, each lead observer for a site is trained by the network botanist or phenology PI. Training involves reading the SOPs and conducting phenology observations with trained network personnel until the new observer's measurements are calibrated with the trainer's. Each set of recorded observations are reviewed by weekly or at the end of the season by network staff (CAKN botanist or phenology monitoring PI) for any inconsistencies. Photos taken at the time of observations are used by network staff to check for consistency among observers. Finally, following data entry, the seasonal progression of phenophases are charted and examined for potential inconsistencies.

The annual time commitment for field observations should be no more than 48 hours of work per site (30 minutes of observation time per plot x 2 plots x 3 times per week x 4 months (16 weeks) max = 48 hours). This time commitment is split among observers at a site and over a 3 to 4 month period. Spring observations occur in April and May and fall observations occur in August and September. Data entry and QA/QC takes 4 days per site. With three sites this should take 12 working days and is typically completed by a network seasonal employee and the network botanist in late May/early June and late September. Oversight and coordinating field crews typically requires less than one day of work annually. Data analysis and reporting, which will occur on a 15-year schedule, will take an undetermined amount of time, but one could expect up to 4 months dedicated to analysis or coordination of analysis.

The network principal investigator for vegetation monitoring, in cooperation with the data manager is responsible for assuring and maintaining the highest quality standards for data completeness, quality and then appropriate archiving of project data in an approved Access database. Data are examined annually once the data have been entered and checked by technicians. Summary graphs and statistics are prepared to inspect the data for outliers or unusual values that require further evaluation. This project is accomplished entirely with existing staff and personnel time, with no one is specifically hired to do it. Indeed, local Park personnel carry-out all of the observations in Wrangell-St. Elias, and network personnel just train observers there and then enter and QA/QC the data observed by local park employees.

Data Management

The phenology data is primarily recorded on paper in the field, though it is possible to record data with the tablet PC directly into the aspen phenology Access database. The datasheets are copied and are located in the Fairbanks administrative office. By the end of the spring and fall seasons, respectively, the phenology data is entered into the CAKN aspen phenology Access database. The Access database for the project was created by CAKN (Carl Roland) and Alaska Regional Office GIS personnel (Angie Southwould) and is currently located on the Central Alaska Network specific drive (Q or CAKN drive) with backups on the vegetation data (V or vegdata drive).

Database Description

In this document we will give brief description of the tables and forms within the CAKN aspen phenology database. For details about the fields within the tables see the "design view" of each table in the database. If you are reading this document to learn how to make field measurements, skip this section and read the Standard Operating Procedures 2, 3, and 4.

Tables

There are nine main tables, prefaced with ‘tbl’ in the database and 12 reference tables, prefaced with “ref” and five system tables prefaced with “sys.” In the following list we describe the main tables and reference tables:

tbl_tree_diameter_obs: This table contains tree diameters for each tree in each plot for each tree diameter measuring sample event. The diameter of each tree is recorded in the spring and again in the fall. There is also a column for tree height, though tree height has not yet been recorded.

tbl_tree: This table has the following information about each tree in the study: plot in which the tree occurs, tree tag number, species, gender, date tree was added to study, date and reason tree was retired from study, and any comments made about the tree. This table also contains the tree’s unique id.

tbl_senescence_obs: This table contains the senescence phenophase for each tree in each plot on each sample event date as well as the point-in-time soil measurements made 2005-2011 at each tree. The phenophase of each tree on each sample event is recorded as a check in a yes or no check-box. There is also column here showing the percent of leaves from each tree with leaf miner damage.

tbl_sample_plot: This table has general information about each plot such as in which park the plot is located, a description of the plot, the plot latitude and longitude, plot diameter, slope angle, aspect, elevation, Viereck vegetation classification, and plot establishment and retirement dates.

tbl_sample_event_personnel: This table shows the initials of the personnel and the date and sample data taken.

tbl_sample_event: This table contains all of the sample event data—time of sampling, weather description, air temperature, snow cover and depth and general comments—for each for each sample event in each plot.

tbl_reproductive_obs: This table contains the flowering phenophase for each tree in each plot during each sampling event. The phenophase of each tree for each sample event is recorded as a check in a yes or no checkbox.

tbl_foliar_green_up_obs: This table contains the green-up phenophase for each tree in each plot during each sampling event. The phenophase of each tree for each sample event is recorded as a check in a yes or no checkbox. This table also contains a column for green-up comments for each tree during each sample event as well as the two soil temperatures taken during 2005 to 2011 at each tree during the spring observations.

tbl_digital_photo: This table contains all the information about the photos taken as a part of the aspen phenology monitoring. This table has the photo id, the plot in which the photo was taken, the date the photo was taken, the digital image number, the photo file name, the photo subject description, the photo direction and comments about the photo.

ref_catkins: This table details all possible flowering phenophases from no catkins present to all catkins fallen.

ref_datum: This table lists the datums used to collect GPS data. Thus far, only NAD83 has been used.

ref_event_type: This table shows the three different sample event types—Greenup (flowering and leaf out), Senescence, and Tree Diameter. These are the three event types that can be selected under the personnel tab on the sample event page in the database (see SOP#5).

ref_gender: This table has the two possible tree genders (female and male).

ref_leaf_color: This table has each senescence phenophase choice from all leaves green to all leaves yellow.

ref_leaf_fall: This table details the phenophases of leaf fall from no leaves have fallen to all leaves have fallen. Note that we no longer record leaf fall status and this is an extraneous table.

ref_leaf_out: This table details the phenophases of green-up from no evidence of leaf out to full sized leaves.

ref_nps_unit: This table lists the three parks and the network they make up—Denali, Wrangell-St. Elias, Yukon-Charley, and the Central Alaska Network.

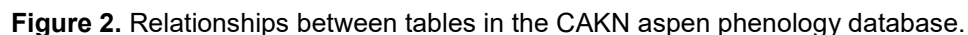
ref_personnel: This table lists the initials, first and last name, job title and years involved with the aspen phenology project for each person who has collected aspen phenology data for the Central Alaska Network.

ref_taxon: This is a list of all vascular and non-vascular plant species in Denali National Park. The table contains various information about each species such as the USDA acronym, family name, Alaska Natural Heritage Program global rank, growth form, etc. The only species of interest in the database, however, is *Populus tremuloides*.

ref_tree_retire: This table lists the reasons for retiring a tree from the project. Currently the only reason to retire a tree is tree mortality.

ref_viereck_class: This table lists a subset of the Alaska vegetation classes. This subset contains all the interior Alaska forest and tall scrub vegetation types.

To see how these tables relate to each other, the relationship page can be viewed below (Figure 2).



There are 14 forms within the CAKN aspen phenology database. We will briefly describe the forms here, however, for data entry purposes, the relevant forms are described in SOP#5.

frm_foliar_greenup_obs: This form is based on the table ‘tbl_foliar_greenup_obs’ and has two drop down boxes that allow you to select the tree number and the leaf out phenophase. There are two fields to enter the two soil temperature readings and two comment boxes for general comments and tree insect and pathogen comments. There is also a check box for tree insects or pathogens.

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frm_sample_event_personnel: This form is where the sample event type (Green-up, Senescence, and Tree Diameter) are selected as well as the person who conducted the sampling.

frm_senescence_obs: This form has three drop down boxes, only two of which we use. The tree number, leaf color phenophase and leaf fall status can be selected from the drop down boxes. We no longer record data on leaf fall status. This form also has two text boxes for the two soil temperatures and boxes for the percent of leaves affected by aspen leaf miners, and comments about insects and pathogens and senescence. There is also a check box for insects or pathogens noted.

frm_summary_help: This is an information text page describing the purpose of the ‘summary form,’ how certain summary values are calculated and how to use the form.

frm_tree_diameter_obs: The record source for this form is the ‘tbl_tree_diameter_obs.’ This form has a drop down box to select the tree number and text boxes to fill in the tree DBH, height, and comments.

ufrm_login: This form tracks the username of the person using the computer. It is not meant to be seen, but because of Access security features the form is visible and the user just needs to close the login box without entering anything.

ufrm_menu: This form is the main page of the database. Access to all other forms to enter data occurs through this form.

ufrm_prompt: This form’s function is not clear.

ufrm_sample_event: This form is used to create new sample events by entering the date on which data was collected or to update already entered sample data by selecting the date on which that data was taken.

ufrm_sample_plot: This form is used to add new sample plots and to supply general information about sample plots such as park the plot is in, when it was established, a general plot description, the plot vegetation type, GPS information, slope angle, aspect, and elevation.

ufrm_summary: This form is used to generate data summaries to track what proportion of study trees are in particular phenophase on a particular date.

ufrm_tree: The record source data for this form is ‘tbl_tree.’ This form has a drop down box to pick the species code (which is always poptr) and a drop down list to choose the tree gender and text boxes to enter when the tree was added to the study, when it was removed and why as well as a comment box.

Data QA/QC

To insure the quality of our monitoring data we rely on adherence to this protocol, our standardized datasheets and careful training of observers and oversight by trained network staff. Network staff intimately familiar with the monitoring protocol are either directly involved with observations or in contact with observers on a weekly to monthly basis depending on the observers familiarity with the

protocol. Data are transcribed by network staff. Transcription errors are minimized by a user friendly MS Access data form. Further errors checks are completed through queries showing the progression of individual trees or plots through phenological stages (Figure 3). These query results allow for detection of potential data entry errors. In Figure 3, there is a clear transition, from ‘no evidence of leaf out’ to ‘has bursting leaf buds’ to ‘has unfurled leaves’ to ‘has full sized leaves.’ If a check mark were not in the expected sequence, such as going “backwards” from unfurled to bursting, we would check if there were a data transcription error or if something unusual happened with that tree. Similar checks are performed at the plot level as well (Figure 4). Finally, additional error checking will occur prior and during data analysis and reporting.

GreenUP QAQC							
plot_id	sample_event_d	tree_ni	greenup_leaf_out_o	has_no_evidence_of_leaf	has_bursting_leaf_bi	has_unfurled_lea	has_full_sized_lea
DENA01	04-25-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	04-27-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	04-29-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-03-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-08-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-10-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-12-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-15-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-17-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-19-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-22-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-24-2006	002 No Leaf Out		☒	☐	☐	☐
DENA01	05-26-2006	002 Bursting and Unfurled		☐	☒	☐	☐
DENA01	05-31-2006	002 Unfurled		☐	☐	☒	☐
DENA01	06-02-2006	002 Full Size		☐	☐	☐	☒
DENA01	06-05-2006	002 Full Size		☐	☐	☐	☒
DENA01	08-14-2006	002 Full Size		☐	☐	☐	☒

Figure 3. Results of a query showing the progression of leaf out phenophases for tree 1 in Denali plot 1.

plot_id	sample_event_d	sample_event_date_r	has_no_evidence	has_bursting_leaf_bu	has_unfurled_leaves	has_full_sized_leaves
FAIR02	03-22-2019	81	1	0	0	0
FAIR02	03-29-2019	88	1	0	0	0
FAIR02	04-01-2019	91	1	0	0	0
FAIR02	04-05-2019	95	1	0	0	0
FAIR02	04-08-2019	98	1	0	0	0
FAIR02	04-10-2019	100	1	0	0	0
FAIR02	04-12-2019	102	1	0	0	0
FAIR02	04-15-2019	105	1	0	0	0
FAIR02	04-19-2019	109	1	0	0	0
FAIR02	04-22-2019	112	1	0	0	0
FAIR02	04-24-2019	114	1	0	0	0
FAIR02	04-26-2019	116	1	0	0	0
FAIR02	04-29-2019	119	1	0	0	0
FAIR02	04-30-2019	120	0.769230769230769	0.153846153846154	0	0
FAIR02	05-01-2019	121	0.461538461538462	0.538461538461538	0	0
FAIR02	05-03-2019	123	0	0.923076923076923	7.69230769230769E-02	0
FAIR02	05-06-2019	126	0	0.923076923076923	7.69230769230769E-02	0
FAIR02	05-08-2019	128	0	0.307692307692308	0.692307692307692	0
FAIR02	05-10-2019	130	0	0.153846153846154	0.846153846153846	0
FAIR02	05-13-2019	133	0	0	1	0
FAIR02	05-15-2019	135	0	0	0.846153846153846	0.153846153846154
FAIR02	05-17-2019	137	0	0	0.153846153846154	0.846153846153846
FAIR02	05-20-2019	140	0	0	0	1

Figure 4. Results of a query showing the percentage of trees in Fairbank plot 2 progressing through leaf out phenophases in 2019.

Data Analysis and Reporting

Annual reporting consists of summary graphs of key phenophases and season length (Figures 5, 6, 7). Because of the high interannual variability in the timing of aspen phenology (we have observed up to 30 days of difference for bud burst timing at a single plot during our relatively brief period of observation), 15 years or more of observations are required to detect trends over time. For this reason, the major data analysis and reporting schedule is on the order of every 15 years, though more frequent analysis may occur as warranted. Although 15 years may be insufficient to detect trends over time, it is sufficient to correlate phenophases with climate. Our first major analysis of the data occurred in 2018. Our priority for this analysis was to find a climate index that consistently predicts the data of budburst and then use historical climate records to backcast budburst for our monitoring sites (Figure 8) and throughout the range of aspen in Alaska (assuming we have some validation points for location outside plots). Subsequent analysis will focus on climate or other drivers of senescence and flowering, quantifying the relationship between phenology and radial growth, and performing linear regressions to detect trends over time during our observation period.

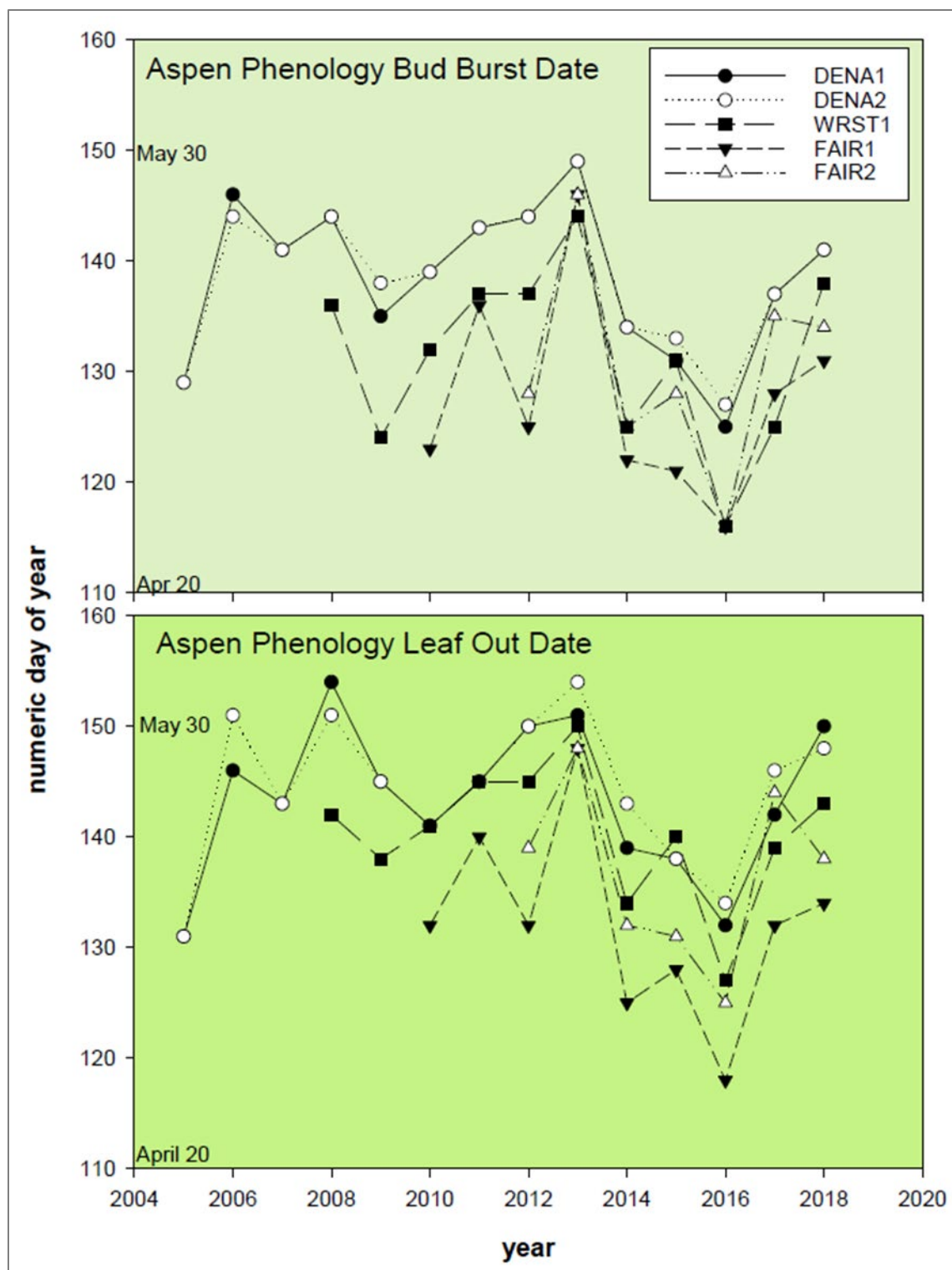


Figure 5. Summary graph of median bud burst and leaf out data for CAKN aspen phenology monitoring plots.

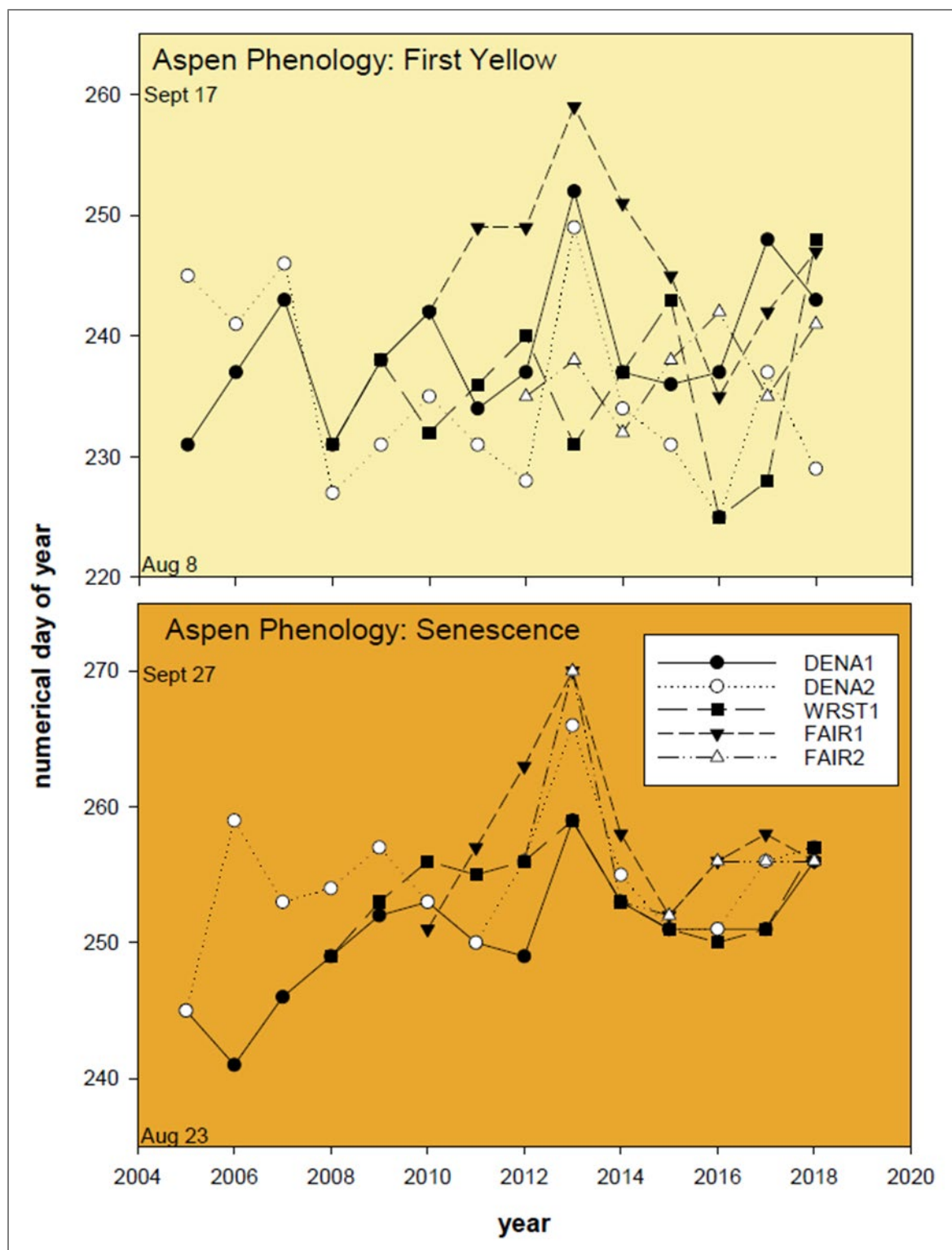


Figure 6. Summary graph of median date of “first yellow” and “senescence” (100% yellow) for CAKN aspen phenology monitoring plots.

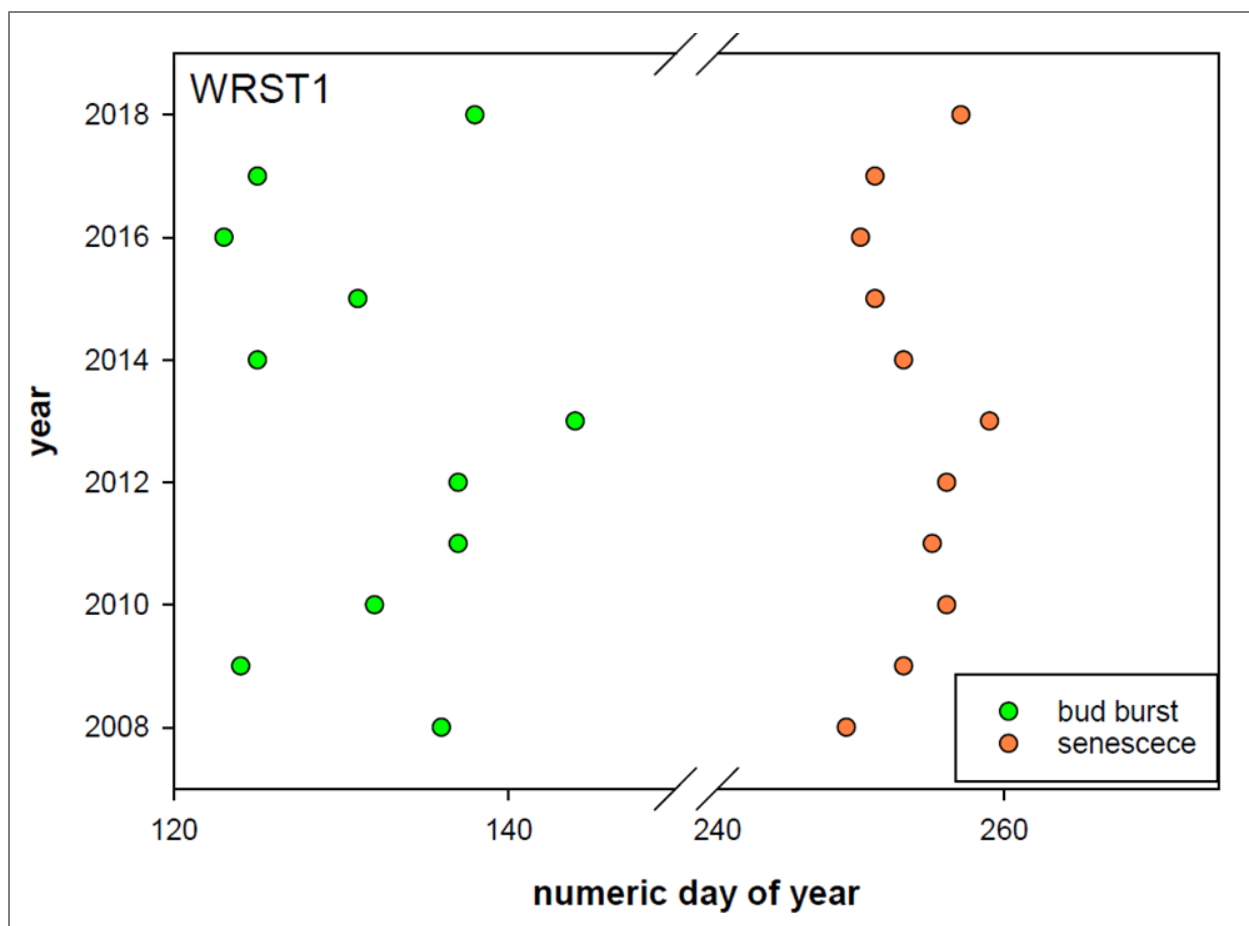


Figure 7. Season length graph for WRST plot 1 showing the median date of bud burst and senescence. Similar graphs are produced annually for each CAKN aspen phenology monitoring plot.

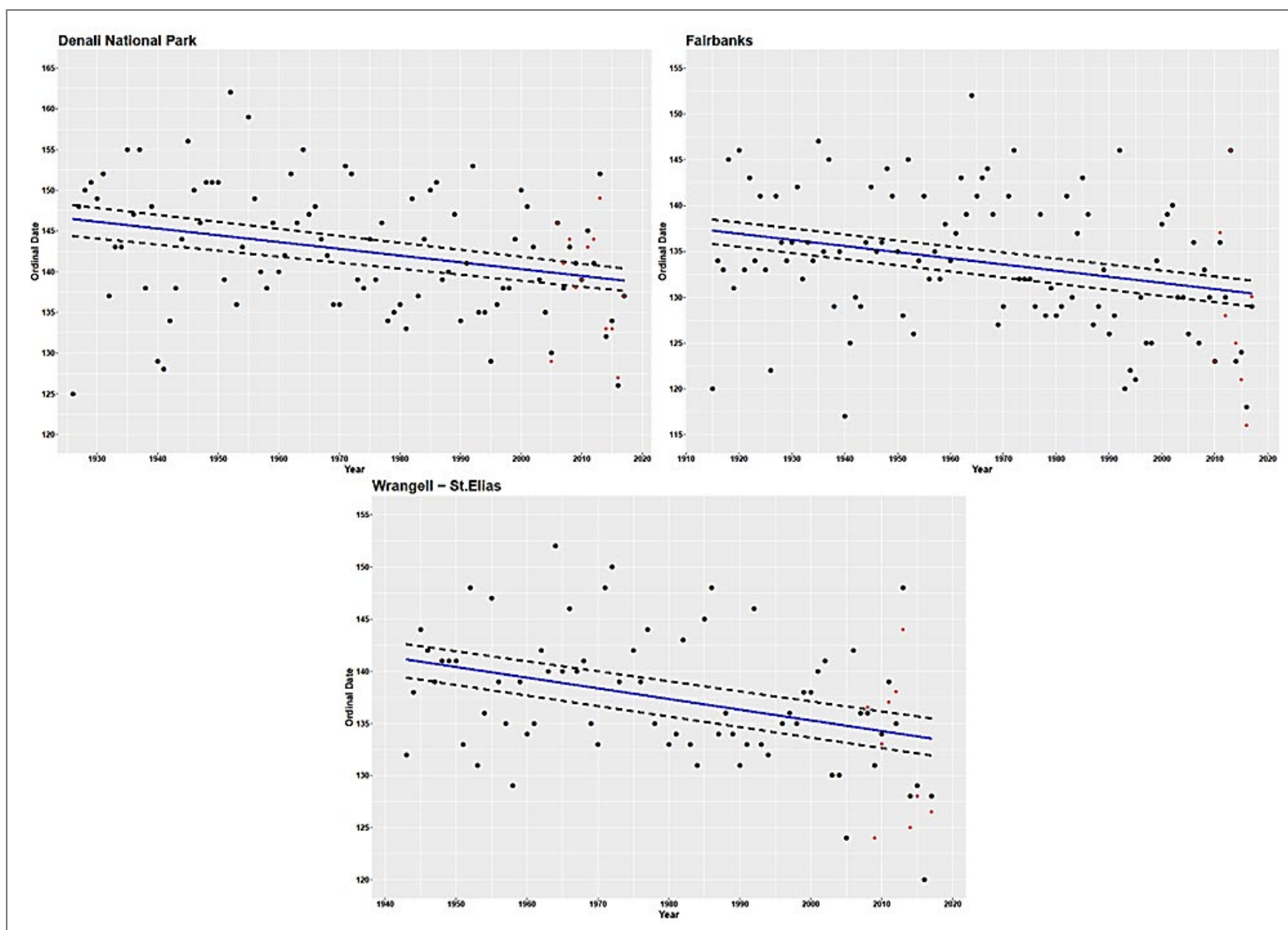


Figure 8. Backcasted ordinal dates of bud burst (black dots) as well as observed dates of aspen bud burst (red dots) for the three CAKN aspen phenology monitoring sites over the period of historical climate records at each site. Significant linear trends show bud burst has advanced 6.7, 8.3, and 10.2 days/century at the Fairbanks, Denali, and Wrangell-St. Elias monitoring sites respectively.

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NPS 953/165141, October 2019

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