# Overview

# Methods

## Study area

## Data

### Phenology information

#### Leaf color change

1. Early color change
2. 50% Color change
3. All leaves changed color

#### Leaf dropping

1. Early dropping
2. 50% leaf drop
3. All leaves dropped

### Tree size

### Climate data

### PRISM

To characterize the climate conditions for each tree, we also obtained monthly precipitation totals, minimum temperatures, and maximum temperature 30-year normals from PRISM ([PRISM Climate Group 2021](#Xc6a61ae9e57c85d16f010348d89f94dac75b6d1)) using the *prism* package ([Hart and Bell 2015](#ref-prism)).

### This chunk of code downloads gridded PRISM data for CONUS. ###  
dir.create(here("Data", "Spatial"))  
dir.create(here("Data", "Spatial", "PRISM"), showWarnings = FALSE) # Create directory to hold data  
prism\_set\_dl\_dir(here("Data", "Spatial", "PRISM")) # tell program to download PRISM data to the directory we just created  
   
# download climate normals  
get\_prism\_normals("ppt", "800m", annual = TRUE, keepZip = FALSE) # annual precipitation

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get\_prism\_normals("tmean", "800m", annual = TRUE, keepZip = FALSE) # annual average temperature

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get\_prism\_normals("tmin", "800m", mon=1, keepZip = FALSE) # minimum temperature in January

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get\_prism\_normals("tmax", "800m", mon=7, keepZip = FALSE) # maximum temperature in Jul

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## Data preparation

### FIELD DATA ###  
#---- Read in excel file that links location\_id field from Budburst with the Locations assigned in the field ----#  
field.data <- read\_xlsx(here("Data", "FieldData.xlsx"), sheet=1)

### BUDBURST DATA ###  
# read in budburst observation csv file  
budburst <- read.csv(here("Data", "budburst\_observations\_1739214151.csv")) %>%   
 # convert observation\_date to date object   
 mutate(date=as.Date(observation\_date, format="%m/%d/%Y")) %>%   
 # pull year and day of year (doy) into separate columns  
 mutate(year =lubridate::year(date), doy=lubridate::yday(date))

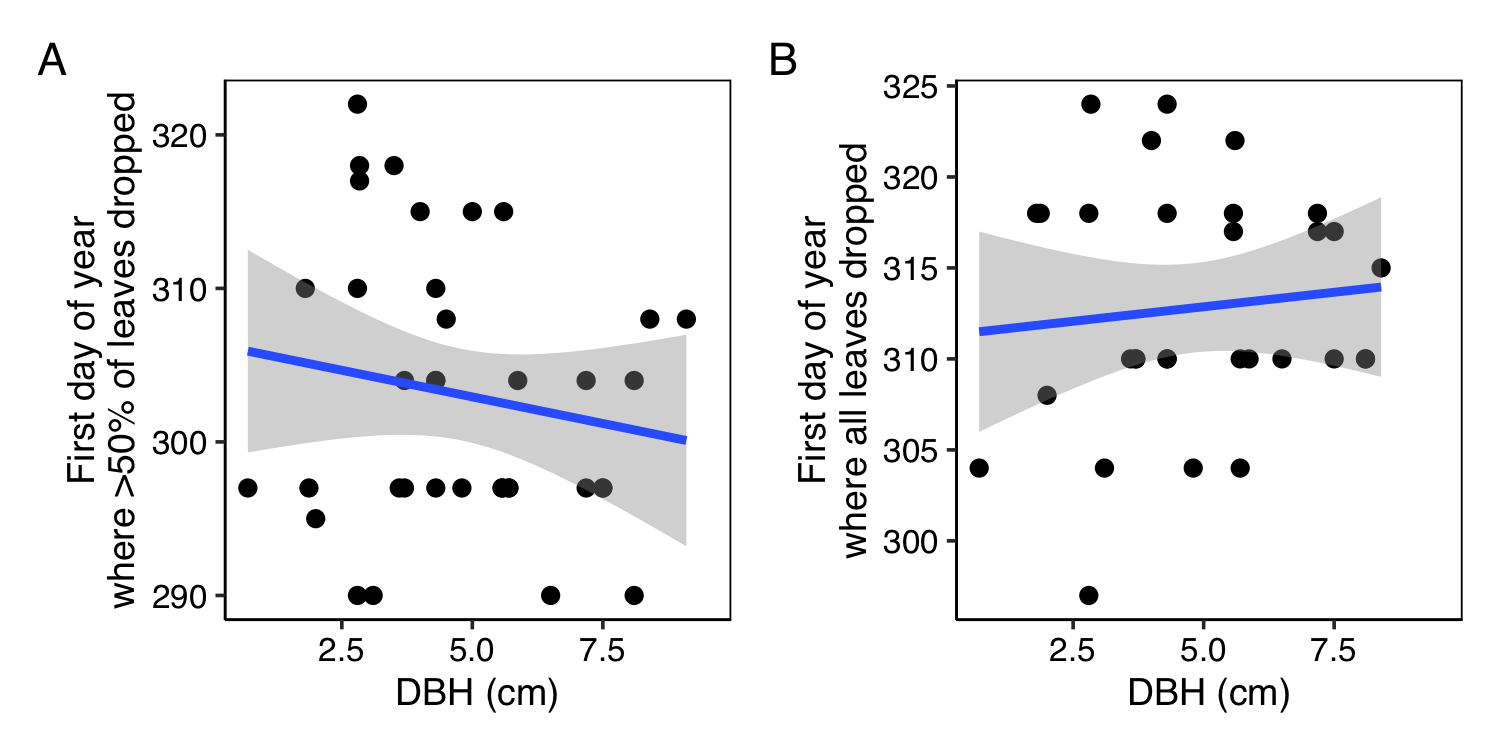
#---- for each tree determine the first day---#  
budburst.sub.firstdate <- budburst %>%   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(first.doy=min(doy))  
  
#---- for each tree determine the last day of observation---#  
budburst.sub.lastdate <- budburst %>%   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(last.doy=max(doy))  
  
#### LEAF COLOR CHANGE ####  
  
#---- for each tree determine the last date when None is reported---#  
budburst.sub.colornone <- budburst %>%   
 # limit dataset to just fall phenophase data describing leaf color  
 filter(phenophase\_plant\_structure %in% c("Autumn Leaf Color Change")) %>%   
 # limit dataset to just observations of 50% Leaf Drop  
 filter(phenophase\_title == "None") %>%   
 # group by location id   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(color.none=max(doy))  
  
#---- for each tree determine the first date when early color change was observed ---#  
budburst.sub.colore <- budburst %>%   
 # limit dataset to just fall phenophase data describing leaf color  
 filter(phenophase\_plant\_structure %in% c("Autumn Leaf Color Change")) %>%   
 # limit dataset to just observations of 50% color change  
 filter(phenophase\_title == "Early color change") %>%   
 # group by location id   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(color.early=min(doy))  
  
#---- for each tree determine the first date when 50% of leaves had changed color ---#  
budburst.sub.color50 <- budburst %>%   
 # limit dataset to just fall phenophase data describing leaf color  
 filter(phenophase\_plant\_structure %in% c("Autumn Leaf Color Change")) %>%   
 # limit dataset to just observations of 50% Color changep  
 filter(phenophase\_title == "50% Color change") %>%   
 # group by location id   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(color.50=min(doy))  
  
#---- for each tree determine the first date when all leaves had changed coloro ---#  
budburst.sub.colorall <- budburst %>%   
 # limit dataset to just fall phenophase data describing leaf color  
 filter(phenophase\_plant\_structure %in% c("Autumn Leaf Color Change")) %>%   
 # limit dataset to just observations of All leaves changed color  
 filter(phenophase\_title == "All leaves changed color") %>%   
 # group by location id   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(color.all=min(doy))  
  
#### LEAF DROP ####  
  
#---- for each tree determine the last date when None is reported---#  
budburst.sub.dropnone <- budburst %>%   
 # limit dataset to just fall phenophase data describing leaf drop  
 filter(phenophase\_plant\_structure %in% c("Autumn Leaves Dropping")) %>%   
 # limit dataset to just observations of 50% Leaf Drop  
 filter(phenophase\_title == "None") %>%   
 # group by location id   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(drop.none=max(doy))  
  
#---- for each tree determine the first date when "Early dropping" is reported ---#  
budburst.sub.drope <- budburst %>%   
 # limit dataset to just fall phenophase data describing leaf drop  
 filter(phenophase\_plant\_structure %in% c("Autumn Leaves Dropping")) %>%   
 # limit dataset to just observations of 50% Leaf Drop  
 filter(phenophase\_title == "Early dropping") %>%   
 # group by location id   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(drop.early=min(doy))  
  
#---- for each tree determine the first date when 50% of leaves had fallen ---#  
budburst.sub.drop50 <- budburst %>%   
 # limit dataset to just fall phenophase data describing leaf drop  
 filter(phenophase\_plant\_structure %in% c("Autumn Leaves Dropping")) %>%   
 # limit dataset to just observations of 50% Leaf Drop  
 filter(phenophase\_title == "50% Leaf Drop") %>%   
 # group by location id   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(drop.50=min(doy))  
  
#---- for each tree determine the first date when all leaves day had dropped ---#  
budburst.sub.dropall <- budburst %>%   
 # limit dataset to just fall phenophase data describing leaf drop  
 filter(phenophase\_plant\_structure %in% c("Autumn Leaves Dropping")) %>%   
 # limit dataset to just observations of All Leaf Drop  
 filter(phenophase\_title == "All leaves dropped") %>%   
 # group by location id   
 group\_by(location\_id) %>%   
 # for each location id calculate the minimum day  
 summarize(drop.all=min(doy))  
   
#---- combine data ---#  
dat.drop <- full\_join(budburst.sub.firstdate, budburst.sub.lastdate, by="location\_id")  
dat.drop <- full\_join(dat.drop, budburst.sub.dropnone, by="location\_id")  
dat.drop <- full\_join(dat.drop, budburst.sub.drope, by="location\_id")  
dat.drop <- full\_join(dat.drop, budburst.sub.drop50, by="location\_id")  
dat.drop <- full\_join(dat.drop, budburst.sub.dropall, by="location\_id")  
dat.drop <- full\_join(dat.drop, budburst.sub.colornone, by="location\_id")  
dat.drop <- full\_join(dat.drop, budburst.sub.colore, by="location\_id")  
dat.drop <- full\_join(dat.drop, budburst.sub.color50, by="location\_id")  
dat.drop <- full\_join(dat.drop, budburst.sub.colorall, by="location\_id")  
  
#---- combine Autumn Leaves Dropping data with DBH ---#  
dat.drop.field <- left\_join(field.data, dat.drop, by="location\_id") %>% group\_by(City, Location, Tree) %>% summarise(Latitude= mean(Latitude, na.rm=T), Longitude=mean(Longitude, na.rm=T), first.doy=min(first.doy, na.rm=T), last.doy=max(last.doy, na.rm=T), drop.none=max(drop.none, na.rm=T), drop.early=min(drop.early, na.rm=T), drop.50=min(drop.50, na.rm=T), drop.all=min(drop.all, na.rm=T), color.none=max(color.none, na.rm=T), color.early=min(color.early, na.rm=T), color.50=min(color.50, na.rm=T), color.all=min(color.all, na.rm=T))  
  
dat.drop.field <- dat.drop.field %>% mutate\_if(is.numeric, ~replace(., is.infinite(.), NA))  
field.dat.sub <- field.data %>% select(City:Location) %>% select(-Name, -ID) %>% unique()  
dat.drop.field <- left\_join(field.dat.sub, dat.drop.field, by=c("City", "Location", "Tree"))

######### This code assigns the climate data to each unique location ###########  
  
### Read in data from budburst and create spatial object with latitude and longitude for each location id  
budburst.sf <- read.csv(here("Data", "budburst\_observations\_1739214151.csv")) %>%   
 # convert observation\_date to date object   
 mutate(date=as.Date(observation\_date, format="%m/%d/%Y")) %>%   
 # pull year and day of year (doy) into separate columns  
 mutate(year =lubridate::year(date), doy=lubridate::yday(date)) %>%   
 # grab certain columns  
 select(location\_id, site\_species\_id, administrative\_area\_level\_1, locality, longitude, latitude, year) %>%   
 # remove duplicates  
 unique() %>%  
 # create spatial object  
 st\_as\_sf(coords = c("longitude", "latitude"), crs = "+proj=longlat +ellps=WGS84 +datum=WGS84 +no\_defs", remove=F)  
  
### Read in prism data  
prism\_set\_dl\_dir(here("Data", "Spatial", "PRISM")) # tell computer where PRISM data is stored  
  
#### ANNUAL PPT ####  
ppt.normal <- prism\_archive\_subset("ppt", "annual normals", resolution="800m") %>% # set what PRISM data we want to look at  
 pd\_to\_file() %>% # get path  
 rast() # read in data   
names(ppt.normal) <- "PPT"  
  
#### ANNUAL TMEAN ####  
tmean.normal <- prism\_archive\_subset("tmean", "annual normals", resolution="800m") %>% # set what PRISM data we want to look at  
 pd\_to\_file() %>% # get path  
 rast() # read in data   
names(tmean.normal) <- "TMEAN"  
  
#### JANUARY TMIN ####  
tmin.normal <- prism\_archive\_subset("tmin", "monthly normals", mon=1, resolution="800m") %>% # set what PRISM data we want to look at  
 pd\_to\_file() %>% # get path  
 rast() # read in data   
names(tmin.normal) <- "TMIN01"  
  
#### JULY TMAX ####  
tmax.normal <- prism\_archive\_subset("tmax", "monthly normals", mon=7, resolution="800m") %>% # set what PRISM data we want to look at  
 pd\_to\_file() %>% # get path  
 rast() # read in data   
names(tmax.normal) <- "TMAX07"  
  
### Overlay budburst observations and extract climate normals  
budburst.sf <- extract(ppt.normal,budburst.sf, bind=T) # PPT  
budburst.sf <- extract(tmean.normal,budburst.sf, bind=T) # TMEAN  
budburst.sf <- extract(tmin.normal,budburst.sf, bind=T) # TMIN  
budburst.sf <- extract(tmax.normal,budburst.sf, bind=T) # TMAX  
budburst.climate <- budburst.sf %>% as.data.frame()  
  
dat.drop.climate <- left\_join(dat.drop, budburst.climate, by="location\_id") %>% mutate(FortCollins=ifelse(locality=="Fort Collins", "yes", "no"))  
write.csv(dat.drop.climate, here("Data", "Processed", "autumnleafdropXclimate.csv"), row.names=F)  
  
###   
dat.drop.field <- dat.drop.field %>% st\_as\_sf(coords = c("Longitude", "Latitude"), crs = "+proj=longlat +ellps=WGS84 +datum=WGS84 +no\_defs", remove=F)  
  
dat.drop.field.climate <- extract(ppt.normal,dat.drop.field, bind=T) # PPT  
dat.drop.field.climate <- extract(tmean.normal,dat.drop.field.climate, bind=T) # TMEAN  
dat.drop.field.climate <- extract(tmin.normal,dat.drop.field.climate, bind=T) # TMIN  
dat.drop.field.climate <- extract(tmax.normal,dat.drop.field.climate, bind=T) # TMAX  
dat.drop.field.climate <- dat.drop.field.climate %>% as.data.frame()  
  
write.csv(dat.drop.field.climate, here("Data", "Processed", "autumnleafdropXfieldXclimate.csv"), row.names=F)

## Analyses

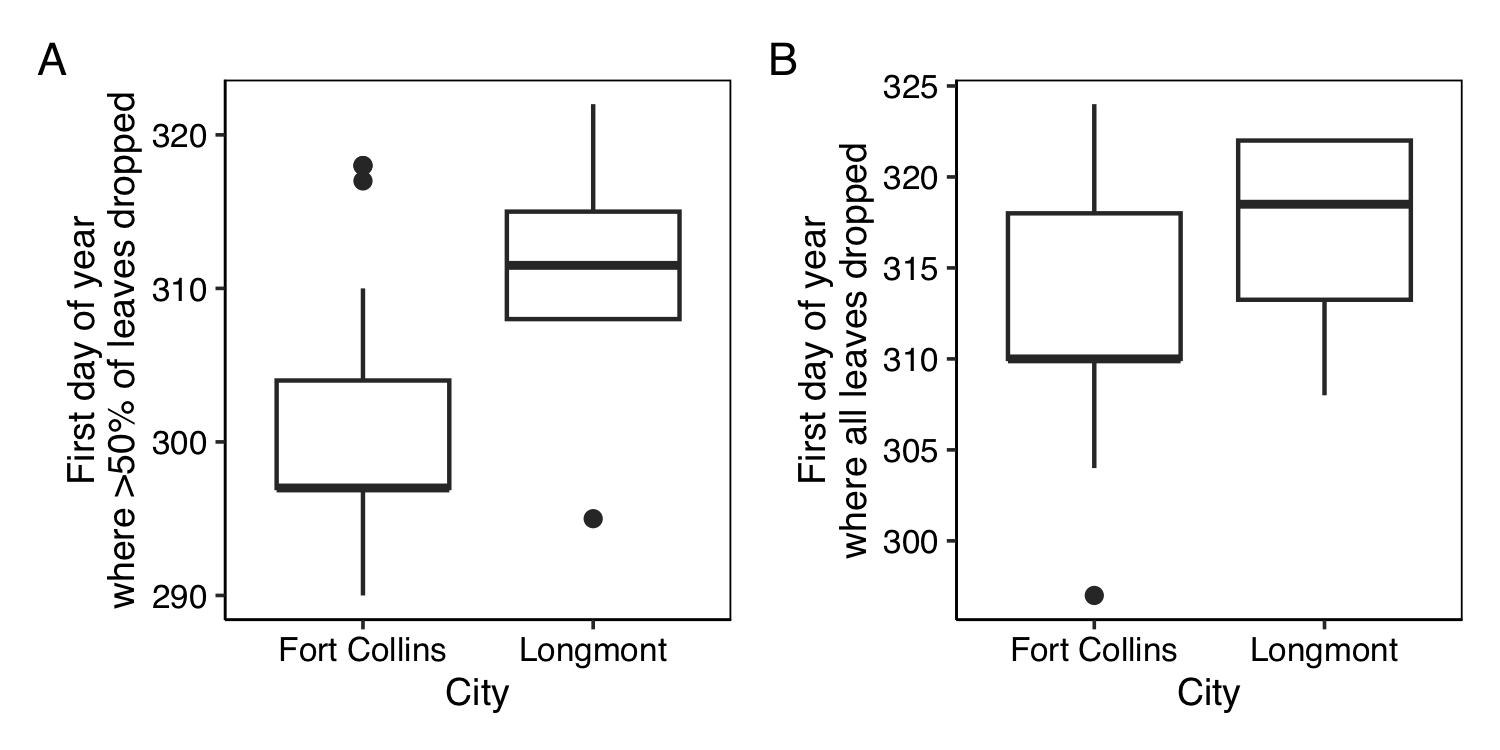
### Were small trees more likely to drop their leaves earlier?

# Create scatter plot of dropall by DBH  
p1 <- ggplot(dat.drop.field , aes(x=DBH, y=drop.50))+geom\_point()+geom\_smooth(method='lm')+xlab("DBH (cm)")+ylab("First day of year\nwhere >50% of leaves dropped")  
p2 <-ggplot(dat.drop.field , aes(x=DBH, y=drop.all))+geom\_point()+geom\_smooth(method='lm')+xlab("DBH (cm)")+ylab("First day of year\nwhere all leaves dropped")  
p1 +p2+plot\_annotation(tag\_levels="A")+ plot\_layout(guides = "collect") & theme(legend.position = 'bottom')



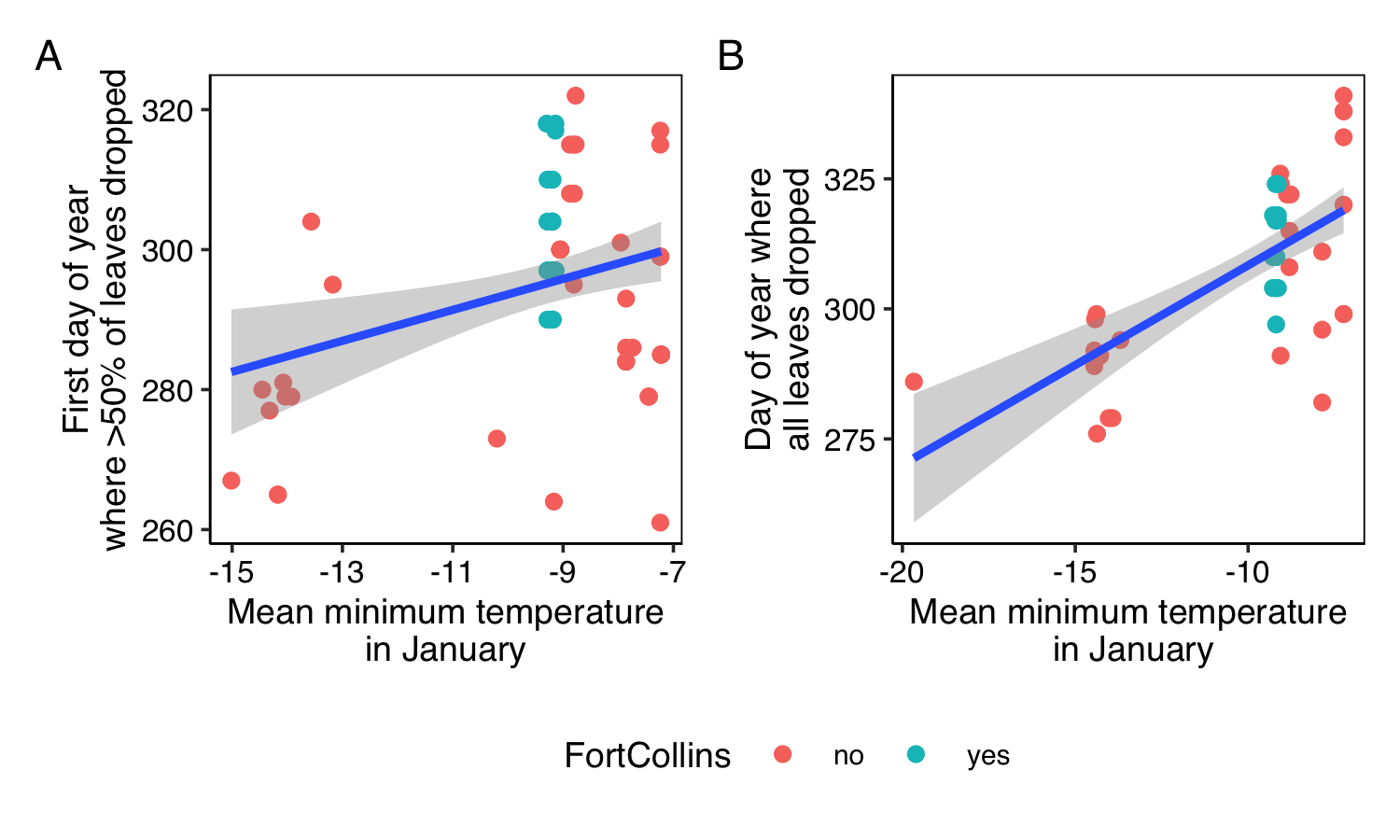
### Did trees in Fort Collins drop their leaves earlier?

# Create boxplot of dropall by city  
p1 <- ggplot(dat.drop.field, aes(x=City, y=drop.50))+geom\_boxplot()+xlab("City")+ylab("First day of year\nwhere >50% of leaves dropped")  
p2 <-ggplot(dat.drop.field, aes(x=City, y=drop.all))+geom\_boxplot()+xlab("City")+ylab("First day of year\nwhere all leaves dropped")  
p1 +p2+plot\_annotation(tag\_levels="A")



### Did trees from cooler climates drop their leaves earlier?

dat.drop.climate <- dat.drop.climate %>%   
 # pull out just data from Colorado  
 filter(administrative\_area\_level\_1 %in% c("Colorado", "CO")) %>%   
 mutate(year=factor(year))  
  
p1 <-dat.drop.climate %>%   
 select(TMIN01, drop.50, FortCollins, year) %>%  
 # pull only dates in Sep to Dec  
 filter(drop.50>243) %>%   
 na.omit %>% # remove na values  
 # plot  
 ggplot( aes(x=TMIN01, y=drop.50))+geom\_point(aes(col=FortCollins))+geom\_smooth(method="lm")+xlab("Mean minimum temperature\nin January")+ylab("First day of year\nwhere >50% of leaves dropped")  
p2 <- dat.drop.climate %>%   
 select(TMIN01, drop.all, FortCollins, year) %>%  
 # pull only dates in Sep to Dec  
 filter(drop.all>243) %>% #  
 na.omit %>% # remove na values  
 # plot  
 ggplot( aes(x=TMIN01, y=drop.all))+geom\_point(aes(col=FortCollins))+geom\_smooth(method="lm")+xlab("Mean minimum temperature\n in January")+ylab("Day of year where\nall leaves dropped")  
  
p1 +p2+plot\_annotation(tag\_levels="A")+ plot\_layout(guides = "collect")& theme(legend.position = 'bottom')



# References

Hart, E. M., and K. Bell. 2015. [Prism: Download data from the oregon prism project](https://doi.org/10.5281/zenodo.33663).

PRISM Climate Group. 2021. [Monthly 30-year climate normals (1981-2010)](https://prism.oregonstate.edu/normals/).