Title of dataset:

Model data for factors limiting the potential range expansion of lodgepole pine in Interior Alaska.

Dataset version and citation

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Abstract

Understanding the factors influencing species range limits is increasingly crucial in anticipating migrations due to human-caused climate change. In the boreal biome, ongoing climate change and the associated increases in the rate, size and severity of disturbances may alter the distributions of boreal tree species. Notably, Interior Alaska lacks native pine, a biogeographical anomaly that carries implications for ecosystem structure and function. The current range of lodgepole pine (*Pinus contorta* var. *latifolia*) in the adjacent Yukon Territory may expand into Interior Alaska, particularly with human assistance. Evaluating the potential for pine expansion in Alaska requires testing constraints on range limits such as dispersal limitations, environmental tolerance limits, and positive or negative biotic interactions. Here, we archive the model results from a multi-disciplinary study. In the study, we used field experiments with pine seeds and transplanted seedlings, complemented by model simulations, to assess the abiotic and biotic factors influencing lodgepole pine seedling establishment and growth after fire in Interior Alaska.

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License

Keywords

boreal forest; climate change; disturbance; experiment; lodgepole pine; Pinus contorta; range limits; simulation modeling; species distribution; wildfire

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Winslow	D	Hansen	0000-0003-3868-9416	Collaborative Research: Climate warming and increasing wildfire in the boreal forests of Northwestern North America: Will vegetation change slow the feedback?	National Science Foundation	OPP 2116863

Timeframe

- Begin date: 04/15/2022
- End date: 03/27/2024
- Data collection: Completed

Geographic location

(GPS or bounding coordinates.

-150.40549° west
-142.0202229°east
66.3151678°north
63.3970094°south

Taxonomic species or groups

Trees

Methods

Extreme fire activity in 2004 produced three large burned areas (total area burned >27,000 km^2) that intersected the road network in Interior Alaska along a broad N–S gradient from the Brooks Range in the north to the Alaska Range in the south. We identified study sites within each of these road-accessible burned areas: the Dalton Complex (DC) along the Dalton Highway north of Livengood, the Boundary Fire (BF) along the Steese Highway east of Fairbanks, and the Taylor Complex (TC) along the Taylor Highway northeast of Tok, Alaska. These roads have infrequent traffic, narrow right-of-ways, and minimal human impact over the last century. We identified 39 intensive study sites (12-13 sites in each burn complex) from a larger sample of 90 sites for detailed studies of post-fire revegetation. Sites captured variation in fire severity (biomass fuel consumption) and gradients in site moisture and elevation within each burned area. All sites were dominated by black spruce when they burned, with >95% canopy mortality caused by fire. We conducted field experiments at these sites with pine seeds and transplanted seedlings, complemented by model simulations, to assess the abiotic and biotic factors influencing lodgepole pine seedling establishment and growth after fire in Interior Alaska.

We used simulations with the model iLand to estimate centennial growth trajectories of lodgepole pine in Interior Alaska and to estimate impacts of pine presence on mean tree biomass and stand-level C stocks, given potential competitive interactions with native tree species. iLand is an individual-based forest process model that simulates the growth and mortality of trees in spatially explicit stands and landscapes based on canopy light interception, climate, and nutrients. Individual trees determine light availability at a 2-m spatial resolution within stands. Climate and soil characteristics (% sand, silt, clay, effective depth, and nutrient availability) are considered to be homogenous at the stand scale (1-ha). iLand is forced with daily temperature, precipitation, shortwave radiation, and vapor pressure deficit. iLand also includes a permafrost and surface SOL module that mechanistically simulates daily changes in active layer depth, annual SOL accumulation and decomposition, and their complex ecological effects. We ran the model in stand mode, independent forest stands are simulated in parallel and neighboring stands do not influence one another. The model simulates each stand as if they are 'wrapped' where trees on one side of the stand influence trees on the other side, eliminating edge effects. The model has been well tested in landscape and stand modes and applied to forest stands containing lodgepole pine in the western United States and deciduous and spruce stands in Alaska.

We initialized iLand with data from 90 boreal forest stands in Interior Alaska. This included the 30 stands used in the lodgepole-pine field experiment and 60 surveyed stands that were also dominated by black spruce before burning in 2004, but where lodgepole pine seedlings were not experimentally planted. Seedling densities of naturally recruiting tree species (black spruce, trembling aspen, and Alaskan birch) were set using field measurements, and we assumed these seedlings and lodgepole pine seedlings were 1 year old and were between 1 and 4 cm tall at the start of the simulations. We initialized lodgepole pine seedlings at densities consistent with the experimental plantings. Lodgepole pine were simulated using a parameter set from the northern Rocky Mountains of the western United States. While species traits can vary across geographic ranges, our initial benchmarking to field data indicated the parameter set was robust for application to interior Alaska. Soil information used to initialize iLand was extracted using geographic coordinates of the 90 stands from the global SoilGrids250m database versions 1.0 (for effective soil depth) and 2.0 (for percent sand, silt, and clay). Relative soil fertility, expressed as plant available nitrogen, was set at 45 kg ha^{-1} yr^{-1}. We used the same interpolated climate data set used in the analysis of the field experiment (Daymet V4) for daily climate data.

We conducted simulations to extend the field experiment for an additional 89 years. This allowed us to quantify how large lodgepole pine would have grown over a century and how the experimental addition of lodgepole pine may have altered the biomass of other tree species and stand-level C stocks.

Stands were simulated with and without experimentally planted lodgepole pine forced with 2005-2015 daily climate randomly recycled with replacement (i.e., no climate change) for a century. To evaluate correspondence with experimental results, we first compared simulated lodgepole pine height and diameter at breast height (DBH) from model year 11 (corresponding to 2015 in the lodgepole pine transplant experiment) with observations at the 30 experimental sites where lodgepole pine seedlings were transplanted. To quantify centennial effects of lodgepole pine, we then used outputs from model year 100 with and without lodgepole pine, to calculate biomass of the naturally occurring tree species, total aboveground live (stem, branch, foliage, regeneration) C stocks, and belowground (SOL, downed wood, coarse roots, fine roots) C stocks.

Data Tables

1. Table name(s): Stand_LP
Table description(s): Stand level output for trees taller than 4 m from simulations that included lodgepole pine

Column name	Description	Unit	Code explanation or date format	Empty value code
Year	Year of simulation			
Ru	Resource unit of stand			
Rid	Resource ID of stand			
Species	Tree species		Pico = Pinus contorta Pima = Picea mariana Bene = Betula neo-alaskana Potr= Populus tremuloides	
area_ha	stockable forest area on the resource unit	ha		
count_ha	Number of stems on RU	#		
dbh_avg_cm	Mean diameter at breast height	cm		
height_avg_m	Mean height of trees	m		
volume_m3	Stem volume	m^3		
total_carbon_kg	Carbon stored in living trees	kg		
gwl_m3	Growth increment	m^3		
basal_area_m2	Basal area of live trees	m^2		
NPP_kg	Total net primary production	kg		
NPPabove_kg	Above ground net primary production	kg		
LAI	Leaf area index	m^2 /m^2		
cohort_count_ha	Number of sapling cohorts in the RU	#		

cohort_basal_area	Mean basal area of sapling cohorts	m^2		

2. Table name(s): Stand_No LP
Table description(s): Stand level output for trees taller than 4 m from simulations that did not include lodgepole pine

Column name	Description	Unit	Code explanation or date format	Empty value code
Year	Year of simulation			
Ru	Resource unit of stand			
Rid	Resource ID of stand			
Species	Tree species		Pima = Picea mariana Bene = Betula neo-alaskana Potr= Populus tremuloides	
area_ha	stockable forest area on the resource unit	ha		
count_ha	Number of stems on RU	#		
dbh_avg_cm	Mean diameter at breast height	cm		
height_avg_m	Mean height of trees	m		
volume_m3	Stem volume	m^3		
total_carbon_kg	Carbon stored in living trees	kg		
gwl_m3	Growth increment	m^3		
basal_area_m2	Basal area of live trees	m^2		
NPP_kg	Total net primary production	kg		
NPPabove_kg	Above ground net primary production	kg		
LAI	Leaf area index	m^2 /m^2		
cohort_count_ha	Number of sapling cohorts in the RU	#		
cohort_basal_area	Mean basal area of sapling cohorts	m^2		

3. Table name(s): Saplingdetail_LP
Table description(s): Stand level output for trees shorter than 4 m from simulations that included lodgepole pine

Column name	Description	Unit	Code explanation or date format	Empty value code
Year	Year of simulation			
Ru	Resource unit of stand			

Rid	Resource ID of stand			
Species	Tree species		Pico= Pinus contorta Pima = Picea mariana Bene = Betula neo-alaskana Potr= Populus tremuloides	
Position	Location of the cell within the resource unit	Ordinal number	a number between 0 (lower left corner) and 2499 (upper right corner) (x=index %% 50; y=floor(index / 50))	
n_represented	Number of individuals represented by the cohort	number		
Dbh	Diameter at breast height	cm		
Height	Mean height of the cohort	m		
Age	Age of the cohort			

4. Table name(s): Saplingdetail_NoLP
Table description(s): Stand level output for trees shorter than 4 m from simulations that included lodgepole pine

Column name	Description	Unit	Code explanation or date format	Empty value code
Year	Year of simulation			
Ru	Resource unit of stand			
Rid	Resource ID of stand			
species	Tree species		Pima = Picea mariana Bene = Betula neo-alaskana Potr= Populus tremuloides	
position	Location of the cell within the resource unit	Ordinal number	a number between 0 (lower left corner) and 2499 (upper right corner) (x=index %% 50; y=floor(index / 50))	
n_represented	Number of individuals represented by the cohort	number		

dbh	Diameter at breast height	cm		
height	Mean height of the cohort	m		
age	Age of the cohort			

5. Table name(s): Sapling_LP
Table description(s): Stand level output recording sapling output in the simulations that included lodgepole pine.

Column name	Description	Unit	Code explanation or date format	Empty value code
Year	Year of simulation			
Ru	Resource unit of stand			
Rid	Resource ID of stand			
Species	Tree species		Pico= Pinus contorta Pima = Picea mariana Bene = Betula neo-alaskana Potr= Populus tremuloides	
count_ha	Number of represented individuals >1.3m height	number		
count_small_ha	Number of represented individuals <1.3m height	number		
cohort_count_ha	Number of cohorts	number		
height_avg_m	Mean height of the cohorts	m		
age_avg	Average age of the cohorts	m		
LAI	Leaf area index	m^2/m^2		

6. Table name(s): Sapling_noLP
Table description(s): Stand level output recording sapling output in the simulations that did not include lodgepole pine.

Column name	Description	Unit	Code explanation or date format	Empty value code
Year	Year of simulation			
Ru	Resource unit of stand			

Rid	Resource ID of stand			
species	Tree species		Pima = Picea mariana Bene = Betula neo-alaskana Potr= Populus tremuloides	
count_ha	Number of represented individuals >1.3m height	number		
count_small_ha	Number of represented individuals <1.3m height	number		
cohort_count_ha	Number of cohorts	number		
height_avg_m	Mean height of the cohorts	m		
age_avg	Average age of the cohorts	m		
LAI	Leaf area index	m^2/m^2		

7. Table name(s): Tree_LP
Table description(s): Individual tree output in the simulations that included lodgepole pine.

Column name	Description	Unit	Code explanation or date format	Empty value code
year	Year of simulation			
ru	Resource unit of stand			
rid	Resource ID of stand			
species	Tree species		Pico=Pinus contorta Pima = Picea mariana Bene = Betula neo-alaskana Potr= Populus tremuloides	
id	Unique id for the tree	number		
x	Location within the ru in the x direction	number		
y	Location within the ru in the y direction	number		
dbh	Diameter at breast height	cm		
height	Height of the tree	m		
basalArea	Basal area of the tree stem	m^2		
volume_m3	Volume of the tree stem	m^3		
age	Age of the tree			
leafArea_m2	Leaf area	m^2		
foliageMass	Mass of tree foliage	kg		

stemMass	Mass of stem	kg		
branchMass	Mass of tree branches	kg		
fineRootMass	Mass of fine root	kg		
coarseRootMass	Mass of coarse roots	kg		
lri	Light resource index	number		
lightResponse	Light response class	number		
stressIndex	Index representing stress			
reserve_kg	Carbon reserves remaining	kg		
treeFlags	Flag for whether tree was targeted for management			

8. Table name(s): Tree_noLP
Table description(s): Individual tree output in the simulations that did not include lodgepole pine.

Column name	Description	Unit	Code explanation or date format	Empty value code
year	Year of simulation			
ru	Resource unit of stand			
rid	Resource ID of stand			
species	Tree species		Pico=Pinus contorta Pima = Picea mariana Bene = Betula neo-alaskana Potr= Populus tremuloides	
id	Unique id for the tree	number		
x	Location within the ru in the x direction	number		
y	Location within the ru in the y direction	number		
dbh	Diameter at breast height	cm		
height	Height of the tree	m		
basalArea	Basal area of the tree stem	m^2		
volume_m3	Volume of the tree stem	m^3		
age	Age of the tree			
leafArea_m2	Leaf area	m^2		
foliageMass	Mass of tree foliage	kg		
stemMass	Mass of stem	kg		
branchMass	Mass of tree branches	kg		
fineRootMass	Mass of fine root	kg		
coarseRootMass	Mass of coarse roots	kg		
lri	Light resource index	number		
lightResponse	Light response class	number		

stressIndex	Index representing stress			
reserve_kg	Carbon reserves remaining	kg		
treeFlags	Flag for whether tree was targeted for management			

9. Table name(s): carbon_LP
Table description(s): Stand level carbon pools from the simulations that included lodgepole pine.

Column name	Description	Unit	Code explanation or date format	Empty value code
year	Year of simulation			
ru	Resource unit of stand			
rid	Resource ID of stand			
area_ha	Stockable area in the resource unit	ha		
stem_c	Carbon in live stems	kg		
stem_n	Nitrogen in live stems	kg		
branch_c	Carbon in live branches	kg		
branch_n	Nitrogen in live branches	kg		
foliage_c	Carbon in live foliage	kg		
foliage_n	Carbon in live nitrogen	kg		
coarseRoot_c	Carbon in live coarse roots	kg		
coarseRoot_n	Nitrogen in live coarse roots	kg		
fineRoot_c	Carbon in live fine roots	kg		
fineRoot_n	Nitrogen in live fine roots	kg		
regeneration_c	Carbon in seedlings and saplings	kg		
regeneration_n	Nitrogen in seedlings and saplings	kg		
snags_c	Carbon in standing snag stems	kg		
snags_n	Nitrogen in standing snag stems	kg		

snagsOther_c	Carbon in branches and coarse roots of standing snags	kg		
snagsOther_n	Nitrogen in in branches and coarse roots of standing snags	kg		
snagsOther_c_ag	portion of carbon that is aboveground	kg		
downedWood_c	Total carbon in downed wood including coarse roots	kg		
downedWood_n	Total nitrogen in downed wood including in coarse roots	kg		
downedWood_c_ag	Portion of downed wood carbon above ground	kg		
litter_c	Carbon in forest floor litter pool including fine roots	kg		
litter_n	Nitrogen in forest floor litter pool including in fine roots	kg		
litter_c_ag	Portion of litter carbon that is above ground	kg		
soil_c	Total carbon in mineral soils	kg		
soil_n	Total nitrogen in mineral soils	kg		
understorey_c	Total carbon in non-tree vegetation	kg		

10. Table name(s): carbon_noLP
Table description(s): Stand level carbon pools from the simulations that did not include lodgepole pine.

Column name	Description	Unit	Code explanation or date format	Empty value code
Year	Year of simulation			
Ru	Resource unit of stand			
Rid	Resource ID of stand			
area_ha	Stockable area in the resource unit	ha		
stem_c	Carbon in live stems	kg		
stem_n	Nitrogen in live stems	kg		
branch_c	Carbon in live branches	kg		
branch_n	Nitrogen in live branches	kg		
foliage_c	Carbon in live foliage	kg		

foliage_n	Carbon in live nitrogen	kg		
coarseRoot_c	Carbon in live coarse roots	kg		
coarseRoot_n	Nitrogen in live coarse roots	kg		
fineRoot_c	Carbon in live fine roots	kg		
fineRoot_n	Nitrogen in live fine roots	kg		
regeneration_c	Carbon in seedlings and saplings	kg		
regeneration_n	Nitrogen in seedlings and saplings	kg		
snags_c	Carbon in standing snag stems	kg		
snags_n	Nitrogen in standing snag stems	kg		
snagsOther_c	Carbon in branches and coarse roots of standing snags	kg		
snagsOther_n	Nitrogen in in branches and coarse roots of standing snags	kg		
snagsOther_c_ag	portion of carbon that is aboveground	kg		
downedWood_c	Total carbon in downed wood including coarse roots	kg		
downedWood_n	Total nitrogen in downed wood including in coarse roots	kg		
downedWood_c_ag	Portion of downed wood carbon above ground	kg		
litter_c	Carbon in forest floor litter pool including fine roots	kg		
litter_n	Nitrogen in forest floor litter pool including in fine roots	kg		
litter_c_ag	Portion of litter carbon that is above ground	kg		
soil_c	Total carbon in mineral soils	kg		
soil_n	Total nitrogen in mineral soils	kg		
understorey_c	Total carbon in non-tree vegetation	kg		

Articles

Walker, X.J., S. Hart, W.D. Hansen, M. Jean, C.D. Brown, F.S. Chapin, III, R. Hewitt, T.N. Hollingsworth, M.C. Mack, J.F. Johnstone. In Press. Factors limiting the potential range expansion of lodgepole pine in Interior Alaska. Ecological Applications.