Climate change effects on forest fire hazards in the wildland-urban-interface of Bhutan

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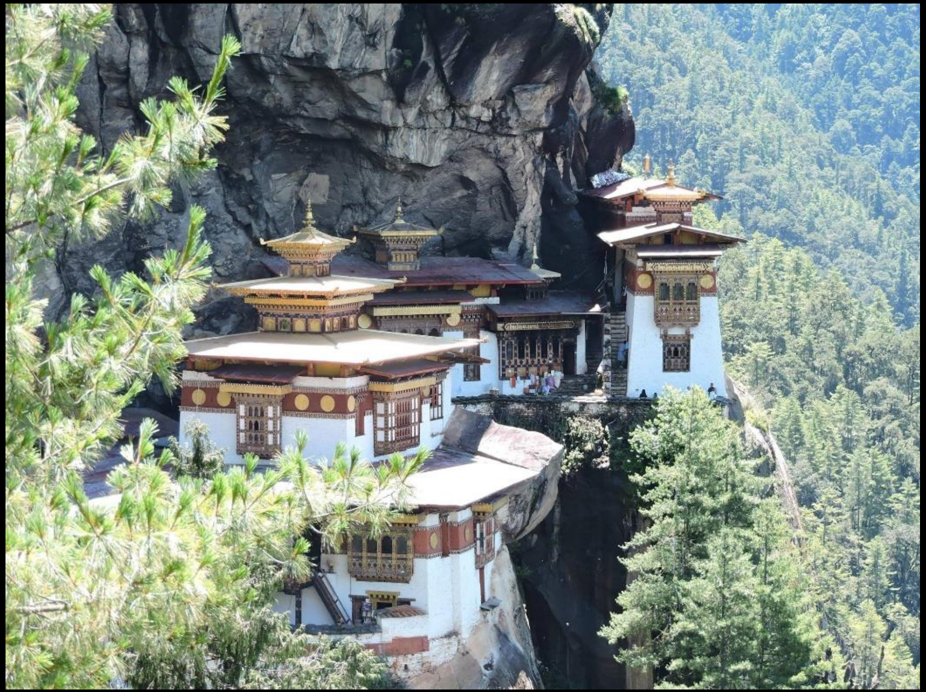

Wildland – Urban – Interface

Camp Fire, Paradise, California
Nov. 2018

86 deaths
18,806 buildings destroyed

Thimphu, Capital of Bhutan

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Climate change effects on wildfire hazards in the wildland-urban-interface – Blue pine forests of Bhutan

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A R T I C L E I N F O

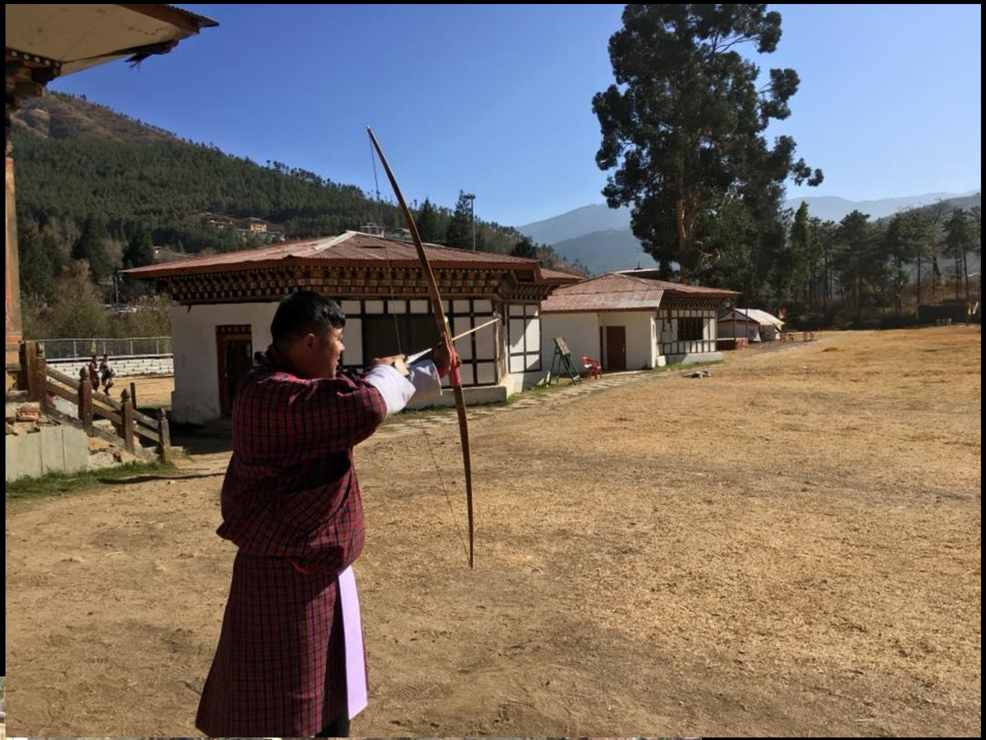
Keywords:
Forest fire
Blue pine
Pinus wallichiana
Fire hazards
Fire behavior
Wildfire simulation
FlamMap
Rural livelihoods
Climate change
Adaptive management
Bhutan
Himalayas

A B S T R A C T

Increased wildfire activity in the Himalayan Mountains due to climate change may place rural livelihoods at risk, yet potential climate change effects on forest fires in this region are poorly investigated. Here we use Bhutan's blue pine (*Pinus wallichiana*) ecosystems to study the sensitivity of fire behavior to climatic changes. Wildland fires are one of the biggest threats to forest resources in Bhutan; blue pine ecosystems, in particular, are of high concern because of their importance for rural livelihoods and relatively high frequency of forest fires. Due to the geographical and socioeconomic characteristics of Bhutan, the region is highly sensitive to climate change. We investigated fire hazards in the wildland-urban-interface (WUI) of two valleys in Bhutan (Thimphu and Jakar), where human settlements and infrastructure are surrounded by blue pine forests. We applied FlamMap, a spatially-explicit wildfire simulation model, to simulate fire behavior under four climate scenarios. As indicators of fire behavior, we used flame length, rate of spread, crown fire activity, burn probability, and fire size. With the simulation outcomes we constructed a fire hazard map showing the hotspots of forest fire susceptibility. FlamMap predicts a two-fold increase in fire hazards in the WUI for both study areas owing to climatic changes. The capital city of Thimphu has, on average, greater fire hazards than Jakar, though fire hazards are spatially variable within both study areas. Our study contributes to the understanding of and ability to predict forest fire hazards in Himalayan blue pine ecosystems. The findings will help to more precisely allocate fire management resources in the WUI, plan suburban development to minimize fire risk to livelihoods, and adapt forest management in the face of climate change.

The Kingdom of Bhutan



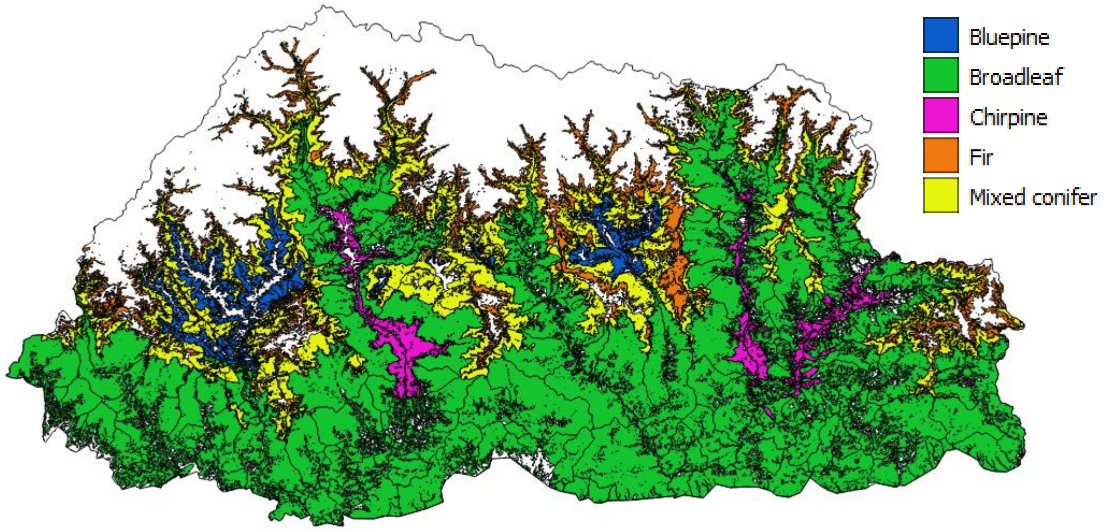


Blue pine forests

Cultural sites are often surrounded by fire-prone forests

Introduction – Blue pine ecosystems

- Bhutan forest cover 70.8%, blue pine covers 3.7%
- Blue pine *(Pinus wallichiana)*:
    - Native to Himalayas; elevation 2100 – 3200 m
    - Early successional species
        - Secondary even-aged stands
        - Most are < 60 years old due to ag abandonment
    - Young trees are highly fire prone
    - Occur in close proximity to settlements



Climate change and Blue Pine

- Bhutan’s climate strongly influenced by monsoons
    - Altered monsoon dynamics, including failures and delays
- Possible increase in fire activity (Gyeltschen 2018)

Young blue pine forests on abandoned agricultural land

Introduction – Research problem and objectives

Climate change is expected to **alter fire regimes**

Blue pine is **very sensitive to wildfire**

Rural livelihoods are **highly dependent** on forest resources

→ Few studies on forest fires in Bhutan

<u>Research goal</u> Investigate the effect of climate change on wildfire hazards in Bhutan's blue pine forests

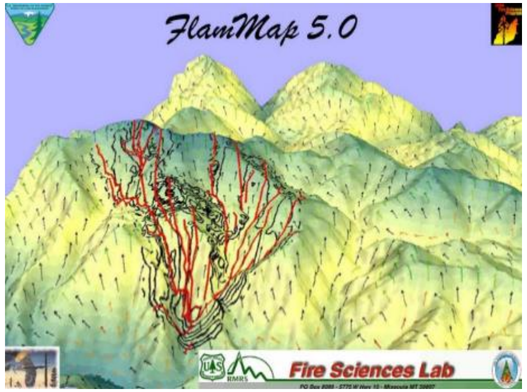
<u>Objectives</u>

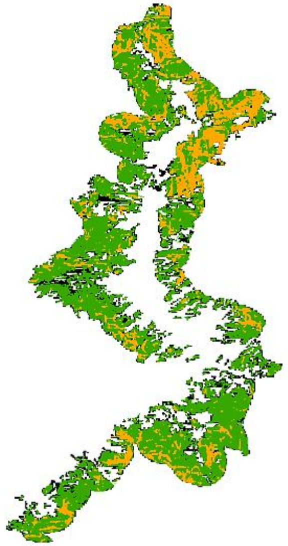
i. Identify effects of climate change on wildfire hazards in the **WUI**
ii. Characterize and map wildfire hazards

<u>Hypotheses</u>

i. Climatic changes (hotter, drier conditions) are likely to increase wildfire hazards
ii. There is strong spatial variability in wildfire hazards between and within study areas

Methods workflow





Data collection → **Data processing** → **Wildfire simulation model** → **Fire hazard index**

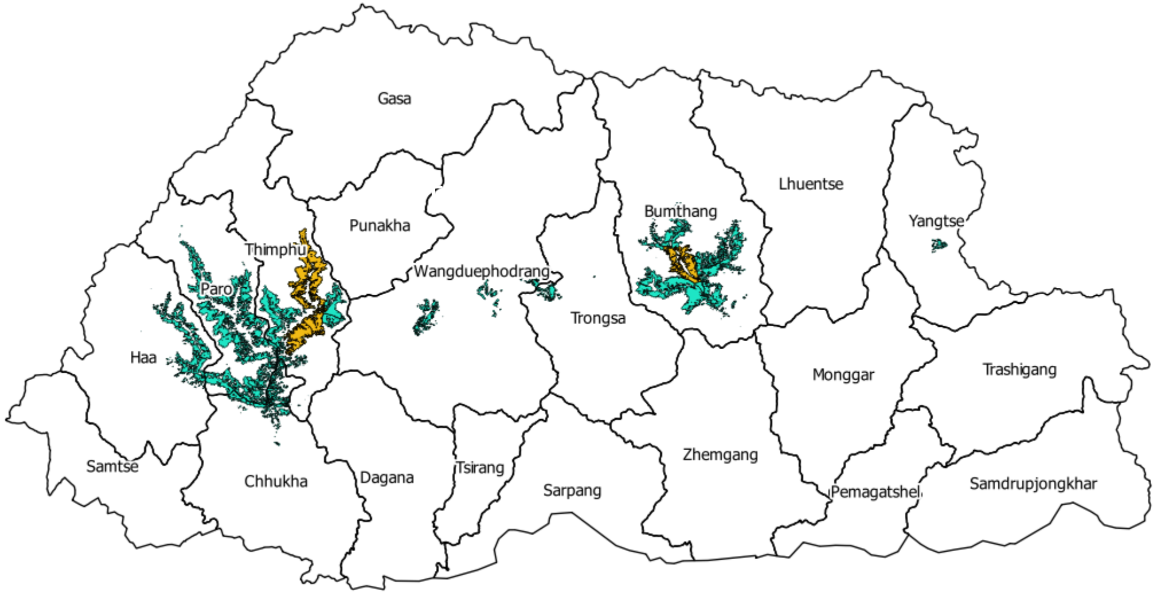
Data collection
- Vegetation/fuel profile
- Topography
- Climate

Data processing
- Fuel structure characterization
- Interpolation to landscape level

Wildfire simulation model
- FlamMap
- Climate scenarios

Fire hazard index
- Fire hazard map

Study area and data collection

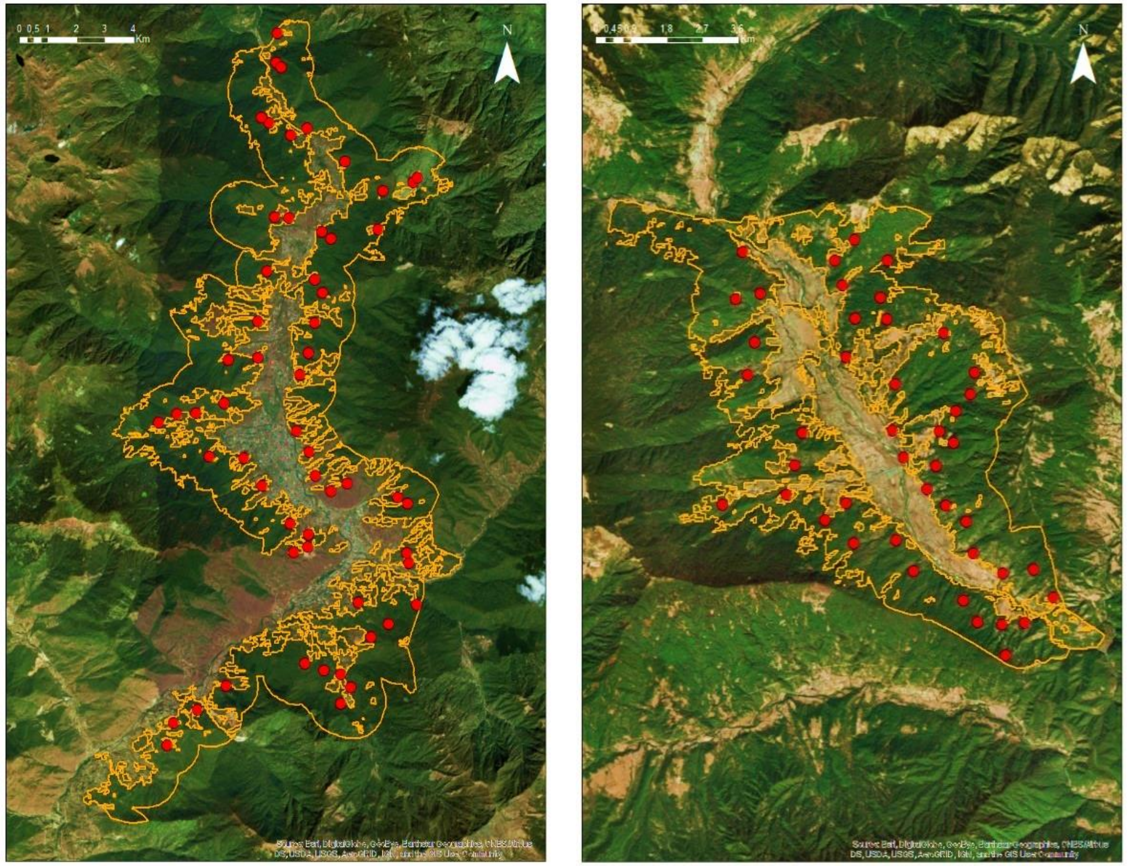


Blue pine forests in Bhutan

Study areas

Total plots sampled

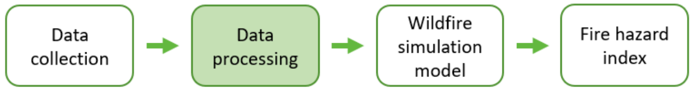
- Thimphu 58 plots
- Jakar 44 plots



Plot distribution in Thimphu (left) and Jakar (right). In orange, borders of the study area.

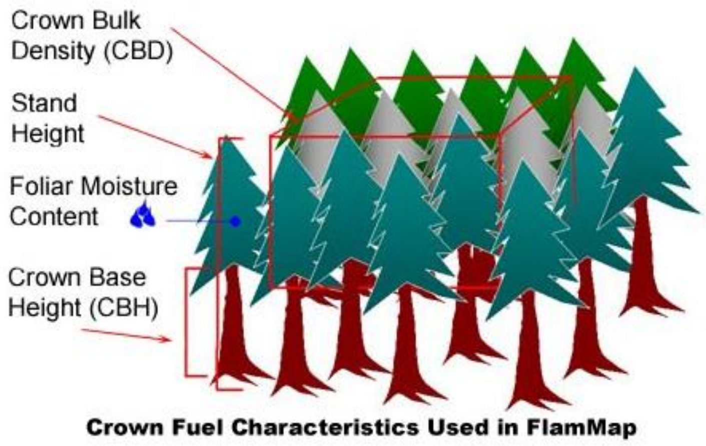
Parameter	Equation
Volume (m^3)	V= BA*TH*FF
Stem biomass (kg m^{-3})	StB= V*SG*1000
Aboveground biomass (kg m^{-3})	AGB= StB*BEF
Standing dead wood biomass (kg m^{-3})	SDW.B= StB*RF
Aboveground carbon (kg m^{-3})	AGC= AGB*0.5
CWD volume (m^3 ha^{-1})	$CWD.V= (pi^2/8L)*\sum d^2*c$
CWD biomass (kg ha^{-1})	CWD.B= CWD.V*SG*1000*RF
CWD carbon (kg ha^{-1})	CWD.C= AGB*CCF
FWD volume (m^3 ha^{-1})	$FWD.V= (kac/L)*\sum d^2$
FWD biomass (kg ha^{-1})	FWD.B= FWD.V*SG*1000
Canopy fuel load (kg m^{-2})	$CFL= ((\sum(fw_i*TEF_i))/10000)*RF$
Canopy bulk density (kg m^{-3})	CBD= CFL/CL
Canopy base height (m)	$CBH= \sum(cbh_i*TEF_i)/ \sum TEF_i$
Equilibrium moisture content (%)	EMC= 2.227+0.16*RH-0.015*T
Moisture content 1h (%)	MC1h= 1.03*EMC
Moisture content 10h (%)	MC10h= 1.28*EMC
Moisture content 100h (%)	$MC100h= YMC100+(BNDRYH-YMC100)*(1-(0.87*exp^{(-0.24)}))$
Herbaceous biomass (Mg ha^{-1})	HB= HCover*2.1262/100
Shrub biomass (Mg ha^{-1})	ShB= ShCover*0.8416/100
Fuelbed depth (cm)	FD= LD + UD
Understory depth (cm)	UD= h-h*((100-C)/100)

Methods – Data processing

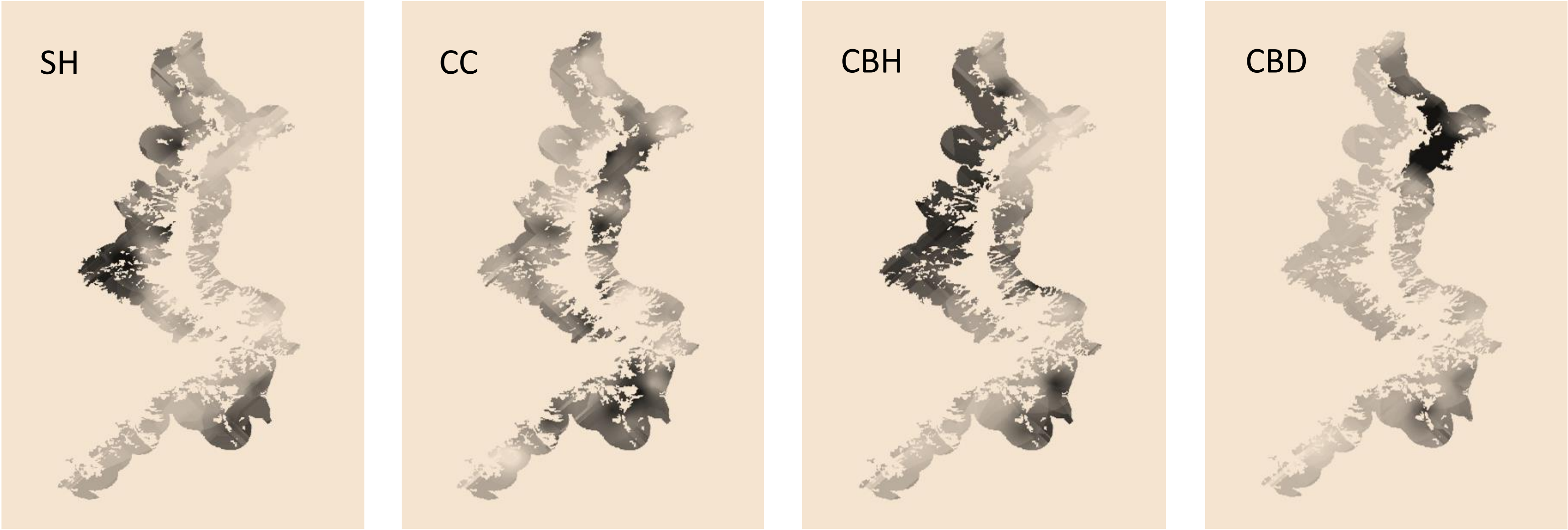


(1) Fuel structure characteristics

- Stand height (SH)
- Canopy cover (CC)
- Canopy base height (CBH)
- Canopy bulk density (CBD)
- CWD and FWD biomass

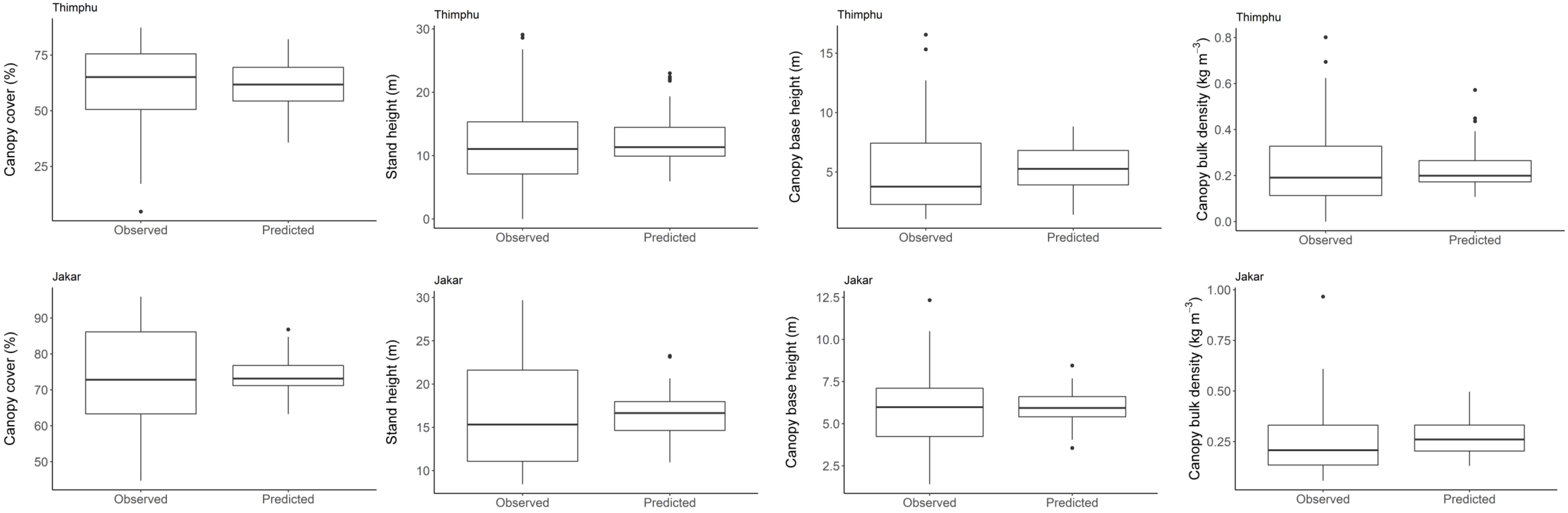


(2) Interpolation to a landscape level → **Kriging** (30x30 m raster layers)

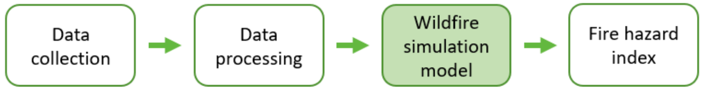


Cross Validation and Krigging Outputs

	Thimphu			
	Canopy cover	Stand height	Canopy base height	Canopy bulk density
Mean prediction error	-0.28	0.075	0.11	0
RMS standardized error	0.97	1.04	0.98	1
RMSE	19.8	6.73	3.74	0.15
	Jakar			
	Canopy cover	Stand height	Canopy base height	Canopy bulk density
Mean prediction error	-0.38	0.15	0.07	0
RMS standardized error	0.97	1.02	1.06	0.99
RMSE	13.71	5.64	2.59	0.18



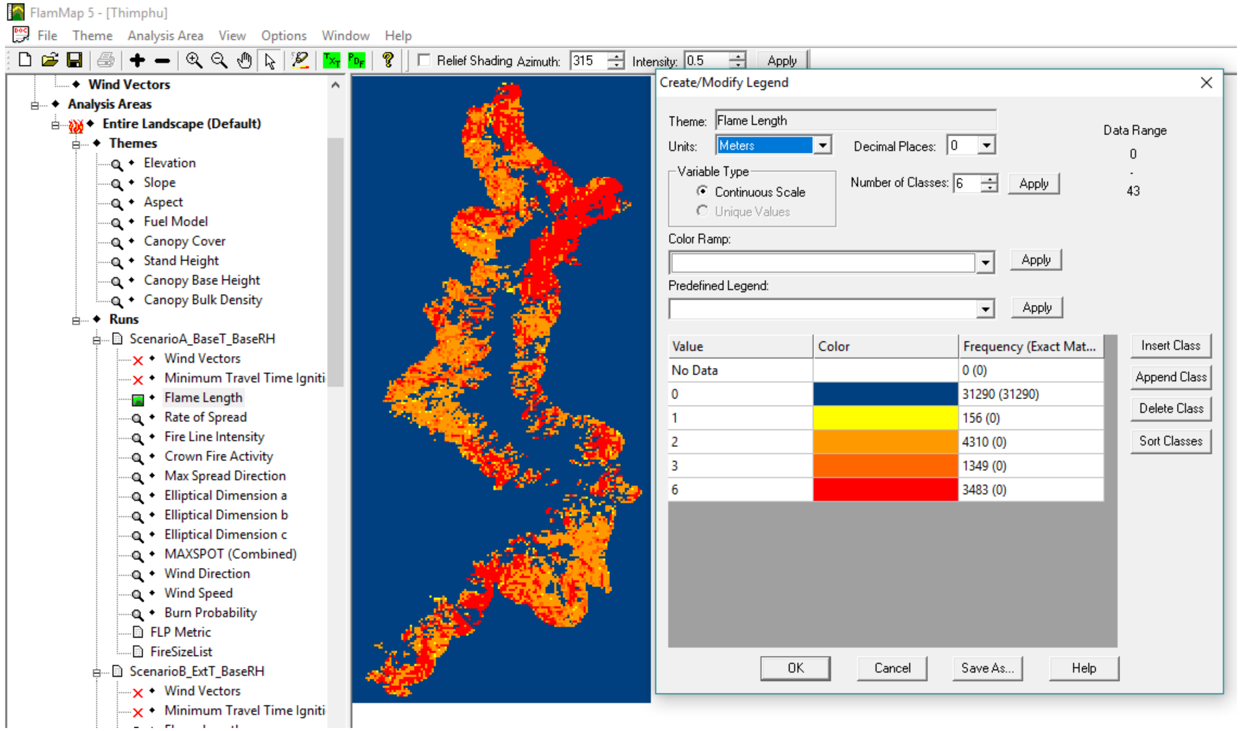
Methods – FlamMap simulation



- Assumed constant environmental conditions
- Assumed all pixels burn; heading fires only
- Fire growth modeled as minimum time algorithm: calculates fastest spread pathway
- Modeled with random ignitions
- Flame length (h) in feet: h= 0.45I^0.46 – I =Fireline intensity
- Burn Probability: ratio between the number of times a pixel burns and the number of simulated fires

Fire behavior indicators:

- Flame length
- Rate of fire spread
- Crown fire activity
- Burn probability
- Fire size



Methods – Wildfire simulation model

Data collection → Data processing → **Wildfire simulation model** → Fire hazard index

Climate scenarios

Symbolize climate change projections of **monsoon failures** and **warmer temperatures**

- **Baseline**: Climate data from 1996 to 2017 (February)
- **Extreme temperature**: 97th percentile baseline weather
- **Extreme RH**: 3rd percentile baseline weather

		Temperature	
		Baseline	Extreme
Relative humidity	Baseline	A	B
	Extreme	C	D

- **Scenario A**: Baseline scenario
- **Scenario B**: Increase in temperature
- **Scenario C**: Decrease in RH
- **Scenario D**: Extreme weather scenario – increase in temperature and decrease in RH

Methods – Wildfire simulation in FlamMap

Data collection → Data processing → **Wildfire simulation model** → Fire hazard index

Input data

weather

- Temperature
- Relative humidity
- Precipitation
- Wind direction
- Wind speed
- Cloud cover

fuels

- Stand height
- Canopy cover
- Canopy base height
- Canopy bulk density
- Fire behavior fuel model
- Fuel moisture content

Raster (stand height, canopy cover, canopy base height, canopy bulk density)

fire behavior

topography

- Elevation
- Slope
- Aspect

Raster

Fire in Thimphu – 27.12.2017

Fire in Thimphu – 2.2.2018

Methods – Fire hazard index

Data collection → Data processing → Wildfire simulation model → Fire hazard index

Fire hazard index

Integration of FlamMap outputs

- Flame length
- Rate of fire spread
- Crown fire activity
- Burn probability

↓

Standardized, log-transformed, re-scaled, summed up

↓

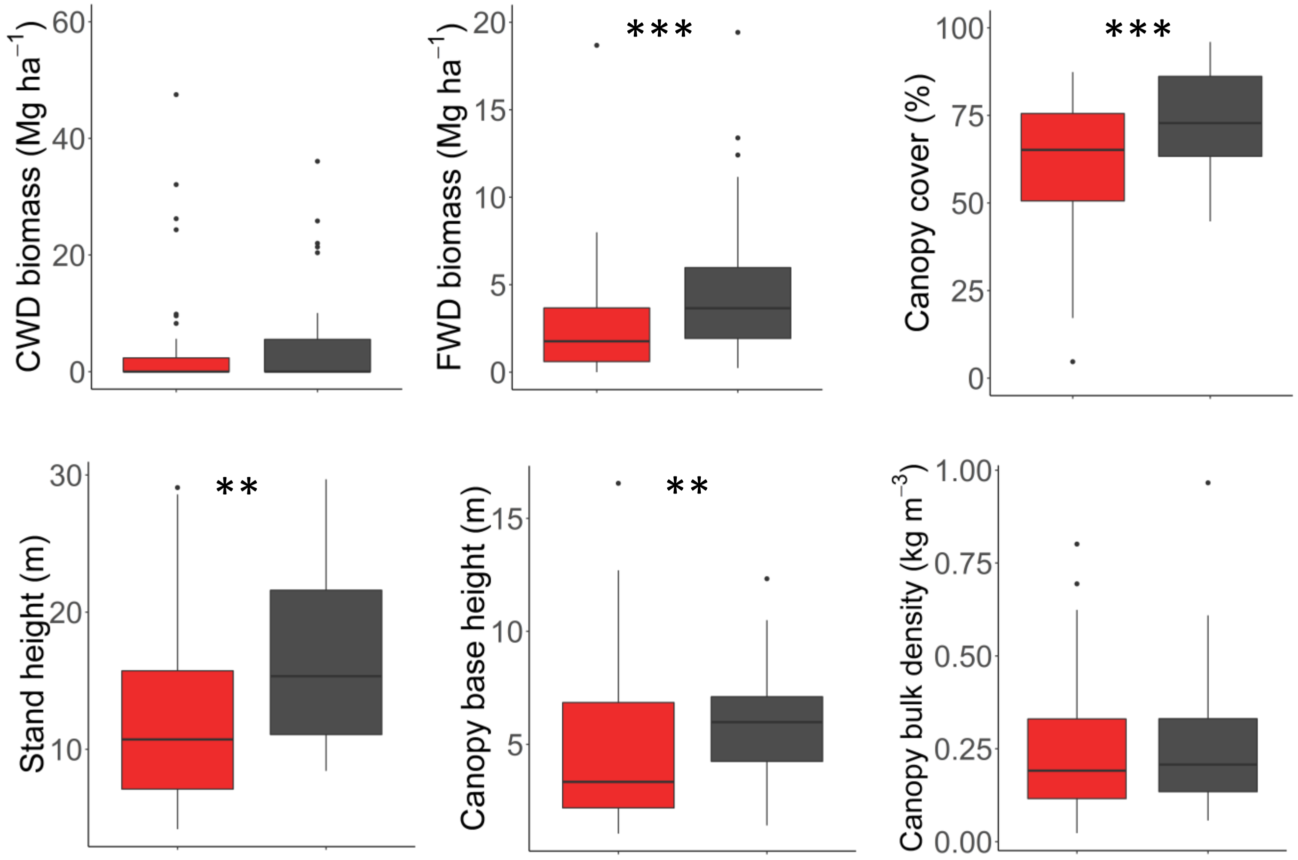
0-1: Low fire hazard

1-2: Moderate fire hazard

2-3: High fire hazard

3-4: Extreme fire hazard

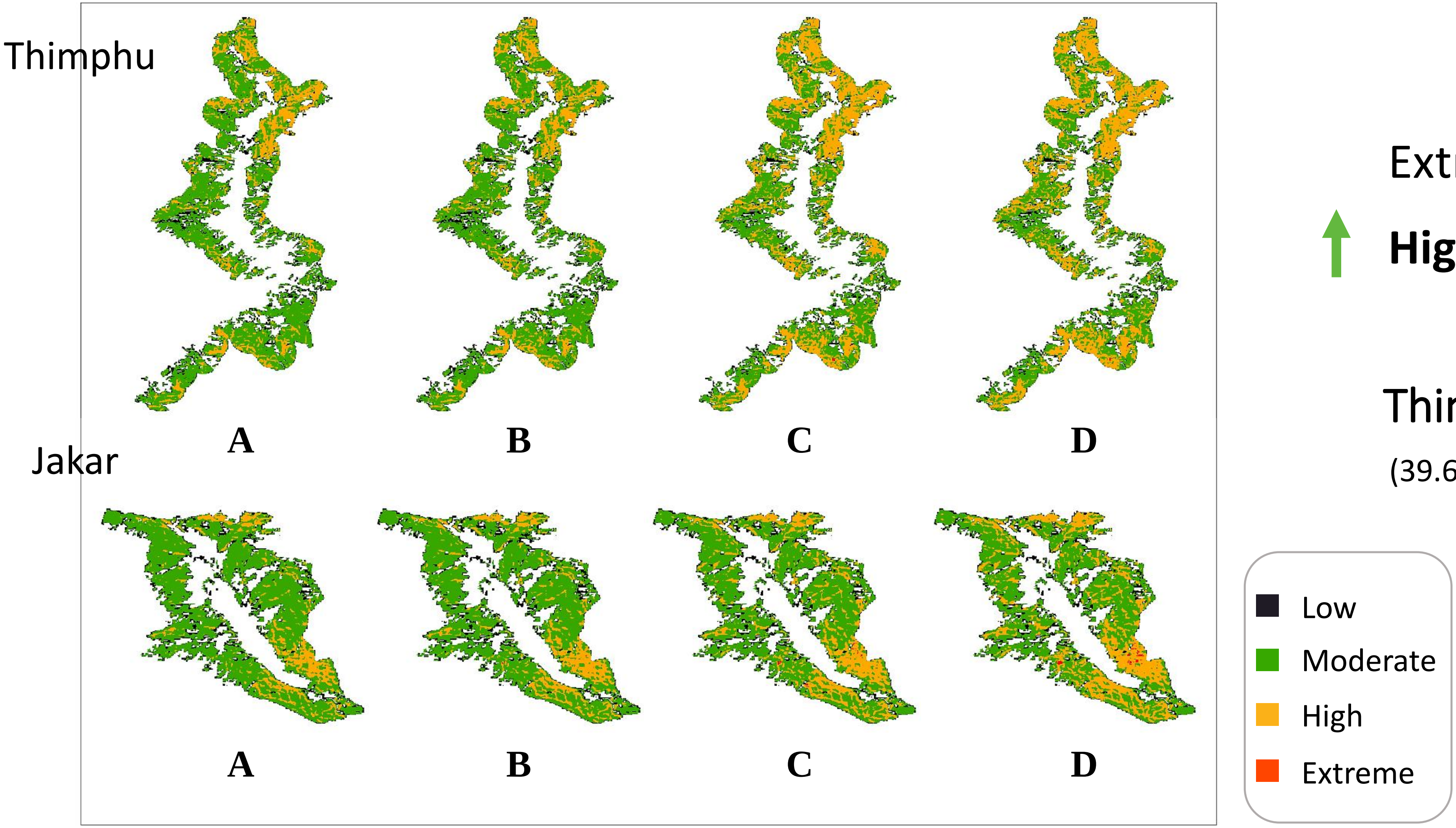
Results – Fuel structure characterization



Jakar > Thimphu
- FWD biomass
- Canopy cover
- Stand height
- Canopy base height

Significance codes:
*: $p<0.05$, **: $p<0.01$, ***: $p<0.001$

Results – Fire hazard index



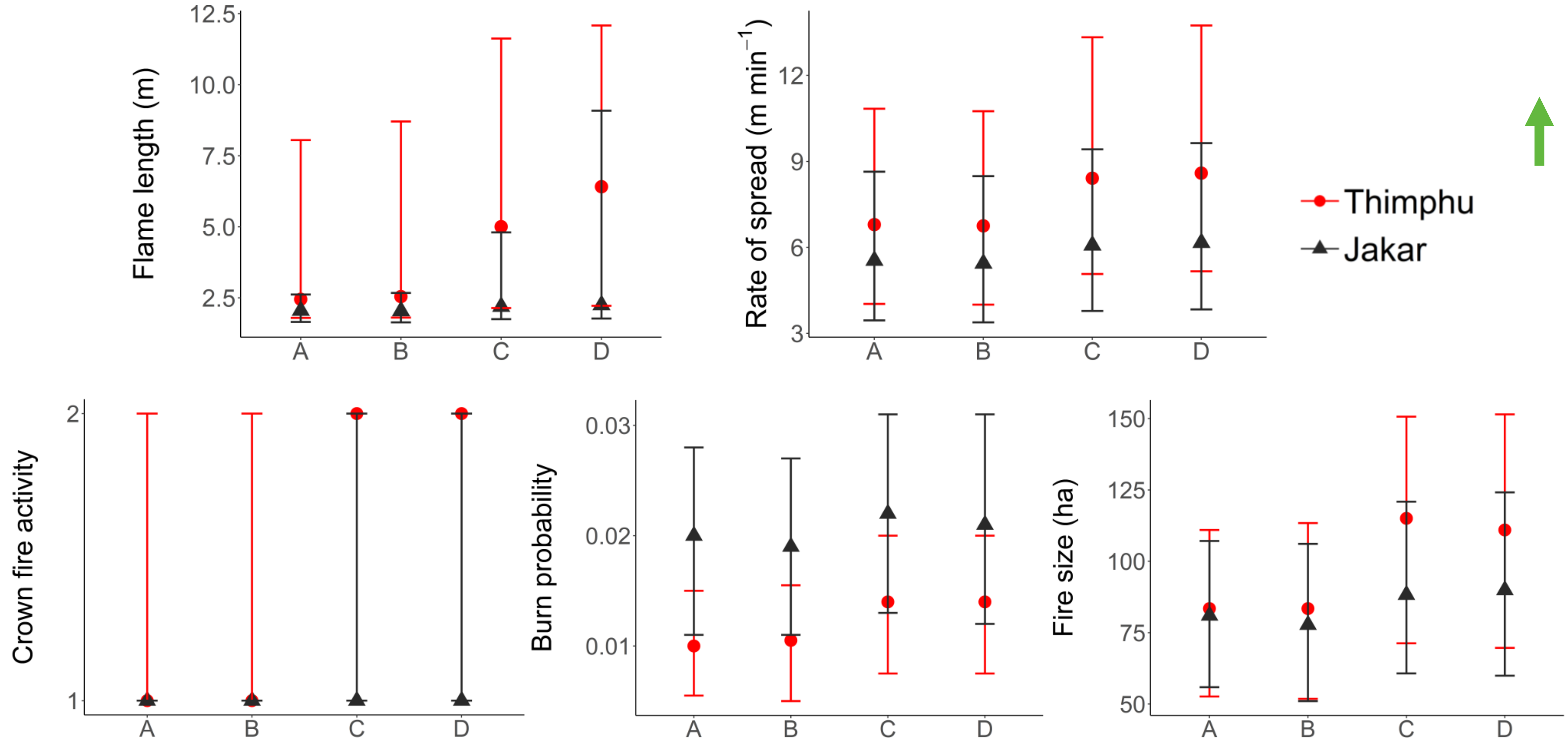
Extreme weather:

↑ **High** fire hazard

Thimphu > Jakar

(39.6% area) (28.8% area)

Results – FlamMap outputs



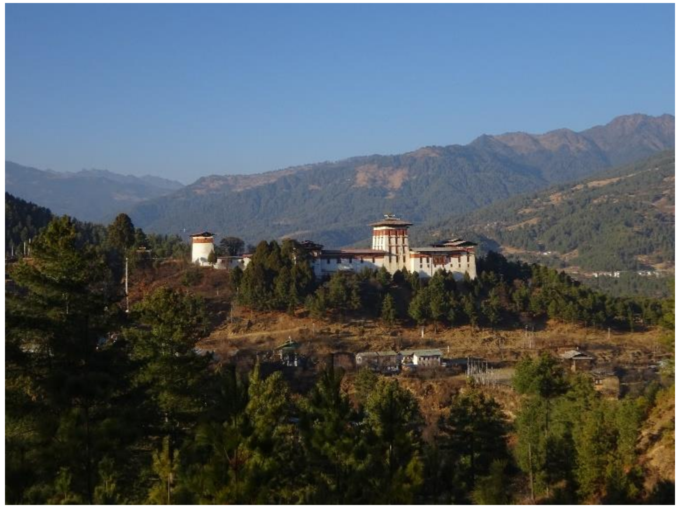
Fire Probability under extreme weather conditions

Relative humidity
(Scenario C)
> Temperature
(Scenario B)

Median and interquartile range of fire behavior indicators per scenario and study area

Discussion

- **Climate change** will likely increase **fire hazard** in blue pine ecosystems
- Continued **expansion of the W.U.I.** poses significant threats, like in the western U.S.
- Alteration of **timing and intensity of precipitation** (monsoon dynamics) will affect fire risks
- Most **extreme weather conditions** have the strongest effect



Recommendations

- Reduce fire hazards through fuels treatment
- Restore older blue pine with greater fire resistance
- Plan or avoid development in areas of high fire hazard
- Improve climate forecasting
- Allocate fire fighting resources accordingly
- Need for international development assistance to improve fire management capacity

Questions?

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