APPENDIX. CONCEPTUAL FRAMEWORK OF MODEL

Introduction

This appendix summarizes the equations and assumptions of each frame type used in the model simulating the effects of erosion, accretion and herbivory. It is included to provide a conceptual idea of how the model functioned and the assumptions we made for each model frame.

Conceptual Framework

River Frame

Assumptions

1. Pixels classified as River can only transitions to bare silt.
2. Accretion of new soils is equal to the probability of erosion. While the rates of erosion and accretion vary with many attributes of the fluvial system, such as soil type, water velocity, and suspended particulates, it can be assumed that bank erosion is proportional to bank accretion in rivers that change little in surface area through time.

Equation to Determine River Movements

The model assigned pixels to the river frame in the simulation regardless of their current frame type according to the following equation:

$$A * \cos(W * (x - \Delta t * D)) \pm \frac{W}{2}$$

Comment [TSR1]: Both wavelength and width are represented with the same term (W). Need to change one – I suggest changing wavelength since width is discussed in the text below.

Parameter	Initial Value	Description
A	800	Amplitude – River bend width (m)
W	2000	Wavelength – Distance between successive river bends (m)
X	-	Column in landscape grid for which river position is calculated
Δt	1	Change in time between river position calculations (yr)
D	0 to 15.1	Erosion/Accretion – Distance river moves in one year

		(m/yr)
W	60	Width of the River (m)

The framework computes the position of the river for a given column (x). Any pixel within 'Width/2' distance of the river will become river and any pixel beyond that distance will either remain unchanged, or become bare silt if it was river previously. Hence Width actually represents the total river width. This gives the position on the x, y plane in meters. This will then be converted to rows by dividing by pixel size, then offset by half the rows in the model.

Bare Soil Frame

Assumptions

1. Pixels classified as bare soil in this model are above mean water level.
2. There are no obstacles to seed dispersal.
3. Bare soil above mean water level is colonized by willow in year 1.

Equation for the Transition to the Willow Frame

Willow initially colonizes bare soil quickly due to its high dispersal through the wind. The density of plants, though relative, is the characteristic used to distinguish young willow communities from bare soil along the Tanana River. Hence, willow density was used to determine when pixels classified as bare soil transition to the willow frame according to the following equation:

$$\frac{dDensity_W}{dt} = W$$

$$Density_{W(t)} = Densiy_{W(t-1)} + \frac{\partial Density_W}{\partial t} * \Delta t * RN$$

Parameters	Initial Value	Description
$\frac{dDensity_W}{dt}$	-	Derivative of willow biomass equation
$Density_{W(t)}$	-	Willow density in the current year of the model (willow/m^2)
W	8	Constant, change in willow density

Δt	1	Time increment (yr)
RN	0 to 1	Random number
$Density_c$	8	Critical willow density (willow/m^2)

Transition Rule:

Transition to Willow Frame when $WillowDensity_t > Density_c$

Willow Frame

Assumptions

1. Willow is the first plant stage of primary succession along the Tanana River.
2. Initial willow biomass is 1 g/m^2.
3. Initially poplar and alder biomass is 1 g/m^2.
4. Nutrients and seeds are distributed equally throughout the landscape.

Equations for the Transition to the Alder Frame

Transition from the willow frame to the alder frame occurs when the ratio of willow biomass to the biomass of later successional species reaches a critical value (Kielland et al. 1998). In field studies, willow communities along the Tanana River were composed of willow (*Salix spp.*), alder (*Alnus tenuifolia*) and poplar (*Populus balsamifera* L.). The growth of willow plants was effected by the presence of herbivory. The model first calculates the effect of herbivory on willow growth (H_W) and on alder and poplar growth (H_{PA}) in relation to the amount low herbivory area observed in field studies.

$$H_W = \frac{\frac{1 - Percent\,Removed}{100}}{\frac{Percent\,Remaining_L}{100}}$$

$$H_{PA} = \frac{1 - H_W}{a + 1}$$

Parameters	Initial Value	Description
H_W	-	Effect of herbivory on willow growth

PercentRemoved	0 to 80	Percentage of twigs removed by herbivores in model simulation
$PercentRemaining_L$	85	Percentage of forage twigs not removed by herbivores in the low herbivory study area
H_{PA}	-	Effect of herbivory on poplar and alder growth
a	0.6	Constant

The model then calculates the change in willow biomass and poplar and alder biomass per year based on observed growth rates on the landscape. Willow biomass was fit to a logistic growth equation after conversion to the natural logarithmic scale.

$$Ln(AGB_W) = M * (1 - e^{(-k*Age)})$$

where, Age is the age of the willow community and M and k are constants. This equation did a reasonable job of explaining variation in the biomass of willow communities based on stand age (R^2 = 0. 88 and 0.92 in the high and low herbivory areas respectively, Figure C1). The derivative of this equation was used to estimate the amount of new willow biomass in model calculations.

$$\frac{dAGB_W}{dt} = k * M * e^{(-M^{(-k*t)} - k*t + M)}$$

Poplar and alder biomass in observed willow communities exhibited exponential growth and were fit to the equation

$$Ln(AGB_{PA}) = x * Age$$

where, age is the age of the willow community observed and x is a constant. This equation fit the observed poplar and alder biomass in field studies (R^2 = 0.93 and 0.77 in the high and low herbivory areas respectively, Figure C2). The derivative of this equation was used in the model calculations to simulate the growth of poplar and alder during each time step.

$$\frac{dAGB_{PA}}{dt} = x * H_{PA} * e^{(x*H_{PA}*t)}$$

Values used in the model for these equations reflect the values observed in the low herbivory area. The herbivory variables then used to modify the change in biomass to mimic the expected growth under the simulated herbivory level.

Parameters	**Initial Value**	**Description**

$\frac{dAGB_W}{dt}$	-	Derivative of the willow biomass equation
$\frac{dAGB_{PA}}{dt}$	-	Derivative of the poplar and alder biomass equation
M	8.55	Logistic equation – maximum willow biomass
K	0.15	Logistic equation – slope of willow biomass
T	-	Stand age
X	0.18	Slope of biomass_{PA} curve

The yearly growth was multiplied by the time interval of the model (Δt), a random number (RN) and added to the biomass currently in the pixel.

$$AGB_{W(t)} = AGB_{W(t-1)} + \frac{\partial AGB_W}{\partial t} * \Delta t * H_W * RN$$

$$AGB_{PA(t)} = AGB_{PA(t-1)} + \frac{\partial AGB_{PA}}{\partial t} * \Delta t * RN$$

Parameters	**Initial Value**	**Description**
$AGB_{W(t)}$	-	Willow above ground biomass in the current model year
$AGB_{PA(t)}$	-	Poplar and alder above ground biomass in the current model year
Δt	1	Time increment
RN	0.5 to 2	Random number between 0.5 and 2 with a mean of 1

The random number was selected from a scale of 0.5 to 2 with a mean of 1 to simulate changes in the growing conditions within a pixel that could result in a 50% reduction of growth in poor years or a doubling of production in good years. Each pixel was then evaluated based on the ratio of willow to alder and poplar biomass to determine if the pixel should be classified as alder.

Transition Rule:

$$BiomassRatio_t = \frac{AGB_{PA(t)}}{AGB_{W(t)}}$$

Transition to Alder Frame if $BiomassRatio_t$ is > $Ratio_c$

Parameters	Initial Value	Description
$BiomassRatio_t$	-	Current ratio of willow to poplar and alder biomass
$Ratio_c$	8	Critical ratio for transition from willow to alder

Alder Frame

Assumptions

1. Willow density decreases during the alder stage and is ignored.
2. Alder biomass/m^2 increases, and then decreases as a function of time.
3. Poplar and spruce are tree species and represent the next stage of succession.
4. The density of tree species dictates the transition to the tree stage.

Equations

Pixels that are classified as alder monitor the density of poplar to determine when to transition into the tree frame. The change in poplar density per year was derived to be P. This value was multiplied by the time step of the model and a random number and then added to the pixels previous poplar density.

$$\frac{dDensity_P}{dt} = P$$

$$Density_{P(t)} = Density_{P(t-1)} + \frac{\partial Density_P}{\partial t} * \Delta t * RN$$

Transition Rule:

Transition to Tree Frame when $Density_{P(t)} > Density_{P(c)}$

Parameters	Initial Value	Description

$\frac{dAGB_W}{dt}$	-	Change in poplar density per year
$Density_{P(t)}$	-	Density of poplar in current year
P	0.181	Constant, change in poplar density
Δt	1	Time increment (yr)
RN	0.5 to 2	Random number from 0.5 to 2
$Density_{P(c)}$	2	Critical density of poplar at which transition occurs

Tree Frame

Poplar and spruce stages were not of interest in this model since they represent the end point of primary succession along the Tanana River, so we did not calculate transition parameters for this successional stage. Once a pixel was classified as mature tree, the pixel retained this value until it was eroded by the river according to transition rules described in the river frame section. As a result, residence time values reported by the model for the tree frame were not considered usable data since the values varied more with number of years simulated then with the herbivory and erosion/accretion rates simulated in modeling exercises.