The i-Tree Cool River Model to Guide Restoration of Thermal Pollution with Riparian Forests & Nature-Based Solutions

Section - Vegetation Benefits: Environmental and Social Benefits Workshop - Vegetation On Levees: Information, Data, and Approaches to Inform Best Practices Coordinator - US Army Corps of Engineering Date & Location - May 2-3, 2023, Arlington, Virginia

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Motivation: Sustaining Riparian Corridors with Nature-based Solutions



Opperman, J.J. and G.E. Galloway. (2022). Nature-based solutions for managing rising flood risk and delivering multiple benefits . *One Earth*. https://doi.org/10.1016/j.oneear.2022.04.012

Endreny, T. A. (2022). i-Tree Tools Assist with Strategically Designing Tree Cover and Improving Community Resilience. *Clear Waters - New York Water Environment Association, 52*(1), 46-50.²

Methods: i-Tree Tools for Nature-Based Solutions



Cool River

Energy

Cool Air

Hvdro

Buffer

i-Tree Tools as Numerical Models: Structure to Value

- i-Tree Vision:
 - To improve forest and human health through user-friendly technology that engages people around the world in enhancing forest management and resiliency.
- i-Tree Goals:



- Calculate how changes in forest structure will lead to changes in functions, ecosystem services, and tradeoffs among benefits and values
- Determine the best tree species, locations, and planting rates to optimize ecosystem services and values through time and across space to enhance human health and well-being

i-Tree Cool River Model: Basic Concepts



Legend: (a) Cross-section view, (b) Longitudinal view w/ (c) Pools and riffles, (d) Planform view P = precipitation, $Q_G = groundwater flow$, $Q_H = hyporheic exchange flow$, $Q_P = pipe or lateral flow$ Φ Sensible = sensible heat flux, Φ Latent = latent heat flux, Φ Sediment = sediment heat flux, Φ LW = long wave radiation, Φ SW = short wave radiation, Φ Total = Sum of all Φ terms, XS = cross section, N = Total XS Eq 1. Advection, Dispersion, Reaction $\frac{\partial T_w}{\partial t} = -U \frac{\partial T_w}{\partial x} + D_L \frac{\partial^2 T_w}{\partial x^2} + R_h + R_i$

Eq 2. Reaction via Heat Transfer $R_h = \frac{\Phi_{Total}}{\rho_w C_p d_w}$

Eq 3. Reaction via External Flows

$$R_{i} = \frac{Q_{G}T_{G} + Q_{S}T_{S} + Q_{H}T_{H}}{\partial t \left(Q_{G} + Q_{S} + Q_{H}\right)}$$

Legend:

 T_w = Temperature of Water, dt = time increment forward, U = velocity in streamwise, dx = distance increment along streamwise, D_L = Dispersion Longitudinal, R_h = Reaction via Heat Transfer, R_i = Reaction via External Inflows, Φ_{total} = Total heat transfer (net radiation, latent, sensible, sediment), ρ_w = density of water, C_p = Specific heat capacity of water constant pressure, d_w = depth of water, Q = discharge or volumetric flow rate, T = Temperature where subscripts G = Groundwater, S= Storm Sewer or Lateral Stream, H = Hyporheic

Abdi, R., & Endreny, T. (2019). A River Temperature Model to Assist Managers in Identifying Thermal Pollution Causes and Solutions. Water, 11(5). doi:10.3390/w11051060; Abdi, R., Endreny, T., & Nowak, D. (2020). A model to integrate urban river thermal cooling in river restoration. Journal of Environmental Management, 258, 110023. doi:https://doi.org/10.1016/j.jenvman.2019.110023

i-Tree Cool River: LA River & Sawmill Creek, NY Fisheries



i-Tree Cool River Prediction of Dissolved Oxygen (DO) with Tree Shade & Green Infrastructure (GI), LA River



Abdi, R., Endreny, T., & Nowak, D. (2020). A model to integrate urban river thermal cooling in river restoration. Journal of Environmental Management, 258, 110023. doi:https://doi.org/10.1016/j.jenvman.2019.110023

i-Tree Cool Air Model: Basic Concepts





Yang, Y., Endreny, T. A., & Nowak, D. J. (2013). A physically based analytical spatial air temperature and humidity model. *Journal of Geophysical Research-Atmospheres, 118*(18), 10449-10463. doi:10.1002/jgrd.50803

i-Tree Cool Air: Washington, DC Heat Wave



Shandas, V., Voelkel, J., Williams, J., & Hoffman, J. (2019). Integrating Satellite and Ground Measurements for Predicting Locations of Extreme Urban Heat. *Climate*, 7(1), 5. 9 Yang, Y., Endreny, T. A., & Nowak, D. J. (2013). A physically based analytical spatial air temperature and humidity model. JGR-Atmospheres, 118(18), 10449-10463. doi:10.1002/jgrd.50803

Discussion: i-Tree Species Suggests Specimens to Plant by Ranking Ecosystem Service Priorities

Location Constraints	Functions Report		
Air Pollutant Remo	val (0-10 importance)		
Rank each of the following e = highly important.	nvironmental services from 0 to 10	on how important these tree se	rvices are to you. 0 = not important; 10
Pollutant Removal			
Carbon Monoxide 📀	Nitrogen Dioxide 🕝	Sulfur Dioxide 🕜	Ozone 🍘
	Q	•	Q
Particulate Matter			
	2 N N		
Select Overall to consider	the overall air pollutant removal impact	of any tree (weights five pollutants b	ased on the estimated effect of each
Select Overall to consider potutant) If you wish to rank the poll Ranking sliders. 10 is mos Other Functions (0-	the overall air pollutant removal impact i utants individually, select Specific to see important while choosing 0 means the -10 importance)	of any tree (weights five pollutants b a list of five pollutants. pollutant will not be considered duri	ased on the estimated effect of each ng species selection
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Select Overall to consider polutarit) Fyou wish to rank the pol Ranking sliders: 10 is mos Other Functions (O- Low VOC Emissions 2	the overall air pollutant removal impact of utants individually, select Specific to see t important while chaosing 0 means the -10 importance) Carbon Storage ? Building Energy Reduction ?	of any tree (weights five pollutants b a list of five pollutants. pollutant will not be considered duri Wind Reduction ? Streamflow Reduction ?	ased on the estimated effect of each ng species selection
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Location Constraints Functions Report

Report

Using your location and the importance of each environmental factor, all of the species in the database are ordered according to your choices based on an algorithm. Species outside of your mature height range and outside of your hardiness zone are dropped from the list.

Report Type

TSUGA

HETEROPHYLLA

- Top 10% shows the best matches.
 All shows the entire ranked list.

ave Report Print Report

Trees Recomm	ended by i	-Tree	Species	S				
This is a list of the top 1 Generated: 5/1/2023 Location: Washington, Dist Hardiness: 7 Constraints:	10% of tree spec	ies base	ed on the fol ites of Americ	llowing fu :a	nctions.			i-Iree
 Minimum Height: None 		 Maxim 	Maximum Height: None					
Air Pollutant Removal (0-10 Importance) Carbon Monoxide: 0 Nitrogen Dioxide: 0 Sulfur Dioxide: 0 		 Ozone Particu 	Ozone: 0 Particulate Matter: 5					
Other Functions (0-10 Importance) Low VOC: 0 Carbon Storage: 0 Wind Reduction: 0 Air Temperature Reduction: 5 		 UV Ra Buildin Strean Low Al 	UV Radiation Reduction: 0 Building Energy Reduction: 0 Streamflow Reduction: 5 Low Allergenicity: 0 S = Sensitive I = Intermediate S/I = Indetermi					
Species					Sensiti	vity		Pest Risk
Scientific Name	Common Name		Hardiness Zone	Invasive	Ozone (O3)	Nitrogen Dioxide (NO2)	Sulfur Dioxide (SO2)	Possible Pests
SEQUOIA SEMPERVIRENS	COAST REDWO	DOD	7 ~ 10					Sudden Oak Death
LIRIODENDRON TULIPIFERA	TULIP TREE		5~9		s			Polyphagous Shot Hole Borer, Spotted Lanternfly
								Southern Pine Beetle, Western Spruce Budworm Heterobasidion Root Disease

- I

Douglas-fir Black Stain Root Disease,

Black Stain Root Disease, Hemloc

WESTERN HEMLOCK 6~7

Software Needs to Work with Other Services and their Valuation: Native Species, Pollinators, Food, Biodiversity, Climate Disruption, Forest Bathing, ...

Discussion: i-Tree Landscape Finds Vulnerability via Overlay of Demographic Data & Ecosystem Services



Exploring 3 Census Block Groups w/ Table of Income Overview & Map Overlay w/ HiRes Tree Cover, LST (Land Surface Temperature) Difference from Median of LandSAT scene. Map & Table show Vulnerability.

Discussion: Leverage Points to Improve the State of our Watershed; Resetting our Paradigms



Watershed state or conditions reveals its purpose.

Endreny, T. A. (2020). Leverage Points Used in a Systems Approach of River and River Basin Restoration. *Water, 12*(9). doi:10.3390/w12092606



https://danceforallpeople.com/haudenosaunee-thanksgivingaddress/haudenosaunee-thanksgiving-address-2/

Today we have gathered and we see that the cycles of life continue.

Conclusions

- Riparian forests restore water & energy balance
- Forest expansion improves human well-being





























Extra Material: Challenges of Modeling Complex (Mal)Adaptive Systems

- Two types of complex adaptive system (CAS):
 - CAS1 systems of nature that adaptively evolve with holistic selection
 - CAS1 systems include individual organisms, or eusocial insect colonies, ecosystem-level microbiomes.
 - CAS2 systems of humans (e.g., socioeconomic system) that may maladaptively evolve due to separate agents pursuing separate goals
 - Can CAS2 internally self-organize into CAS1 or
 - Can CAS2 somehow externally organize into CAS1

Wilson, D.S and Madhavan, G. (2021) Complex Maladaptive Systems, The Bridge SI on Complex Unifiable Systems, National Academy of Engineering, Washington, DC.