Beaver-driven peatland ecotone dynamics: Impoundment detection using Lidar and geomorphon analysis

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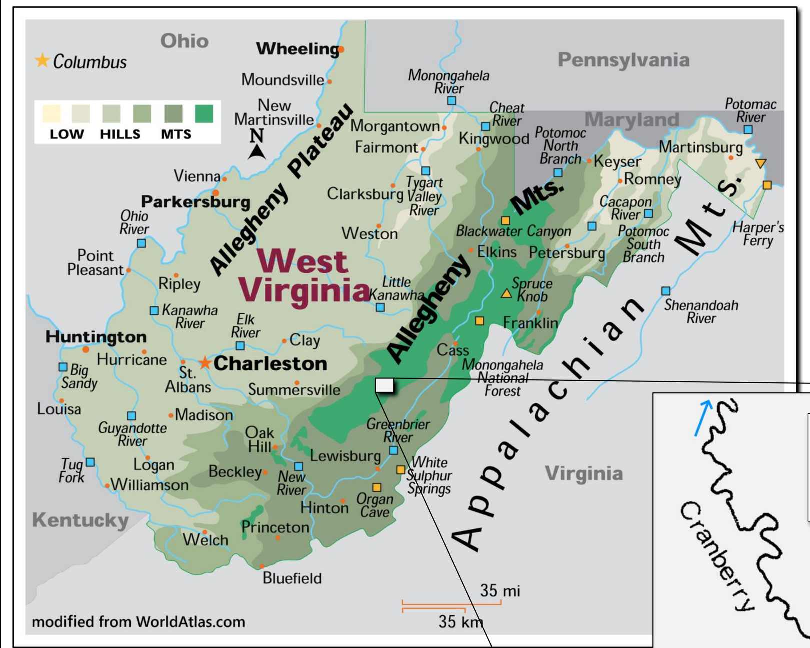
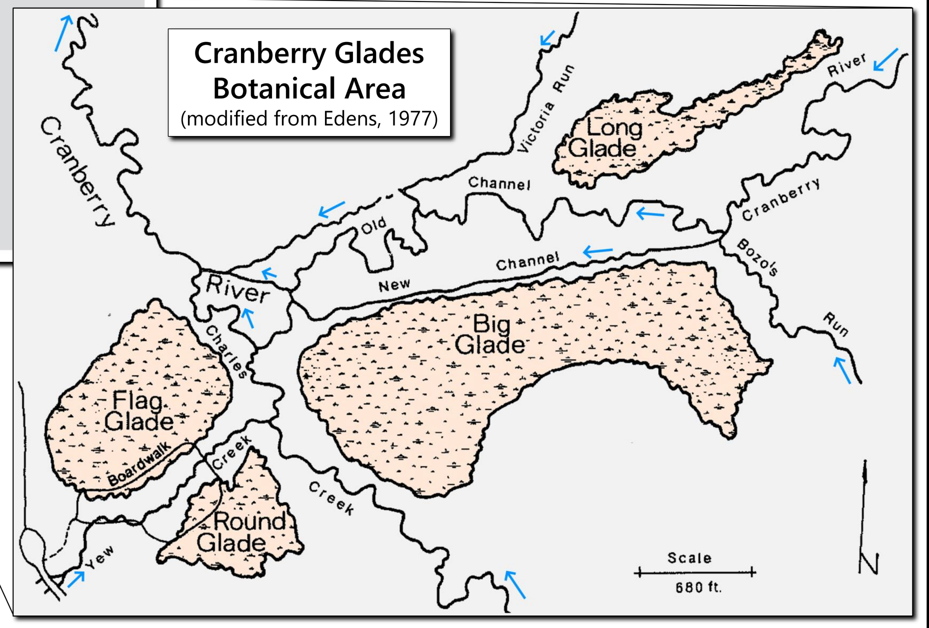
esa Vital Connections IN ECOLOGY 2021

Introduction and main objective



"Crazy how beavers just see running water and just think to themselves 'Well someone has to put a stop to this.'" -Royce Hamm



Beaver (*Castor* spp.) are renowned as ecosystem engineers. Their ponds and vegetation consumption can greatly alter local hydrology and ratios of meadow to woodland. Beaver actively buffer their environments against drought and wildfire susceptibility; moreover, they influence important climate parameters like carbon retention and methanogenesis (Rozhkova-Timina et al., 2018). Beaver populations clearly deserve attention in protected areas owing to their power to change landscapes and ecosystems.

Cranberry Glades Botanical Area, a National Natural Landmark deep in the High Allegheny mountains, protects the largest prehistoric area of open bogs in West Virginia. The Glades have been shrinking for at least a century due to woody encroachment associated with water table drop (Darlington, 1943; Edens, 1977; Meissner, 1981). Stine et al. (2011) suggested beaver have been integral to the formation and maintenance of the Glades' *Sphagnum*-dominated peatland conditions. Edens (1977) hypothesized that an early-1900s combination of local beaver extermination and industrial logging resulted in extensive, excessive runoff and siltation. Human disturbances, beaver population dynamics, and climate change may together have dramatic impacts on the hydrology of the rare peatlands of Cranberry Glades. Monitoring of beaver activity is crucial to the effective management of this imperiled and isolated "Arctic Island."

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Our main objective was to develop a method to remotely identify beaver impoundments. Here, we present and evaluate (qualitatively) a multifaceted approach based on analyses of Lidar imagery, aerial orthophotos, and repeat landscape photography. Our test site includes boreal peatland ecotones within the central 180ha of Cranberry Glades. Geomorphon analysis (Jaziewicz and Stepinski, 2013) is a machine vision terrain classifier applied here at the microtopographic scale in a novel attempt to more reliably detect beaver dams and impoundments.

References

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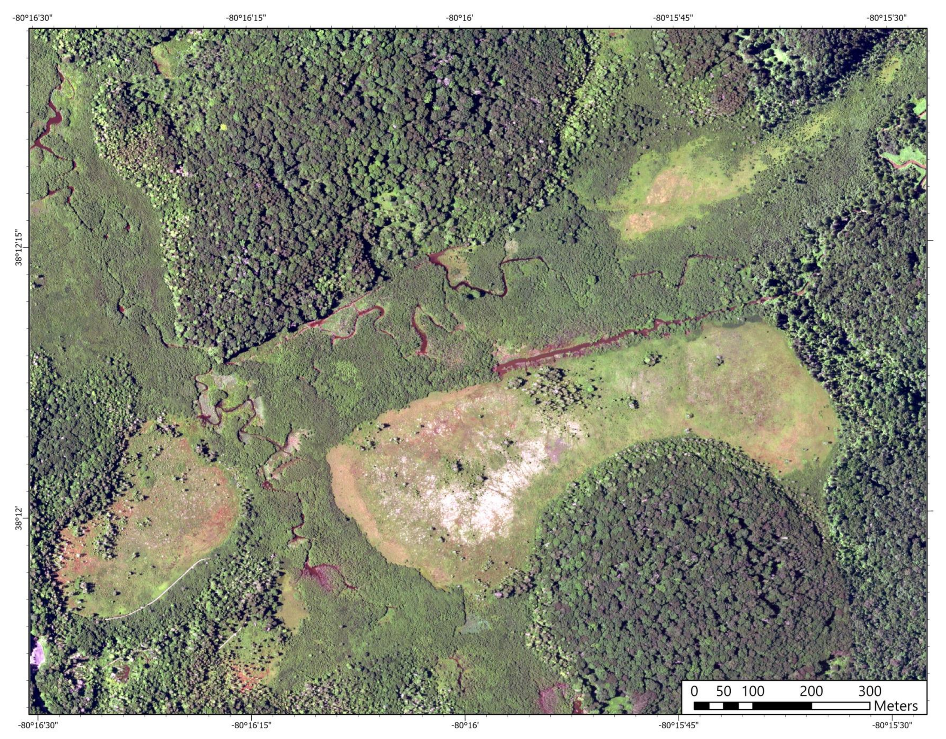
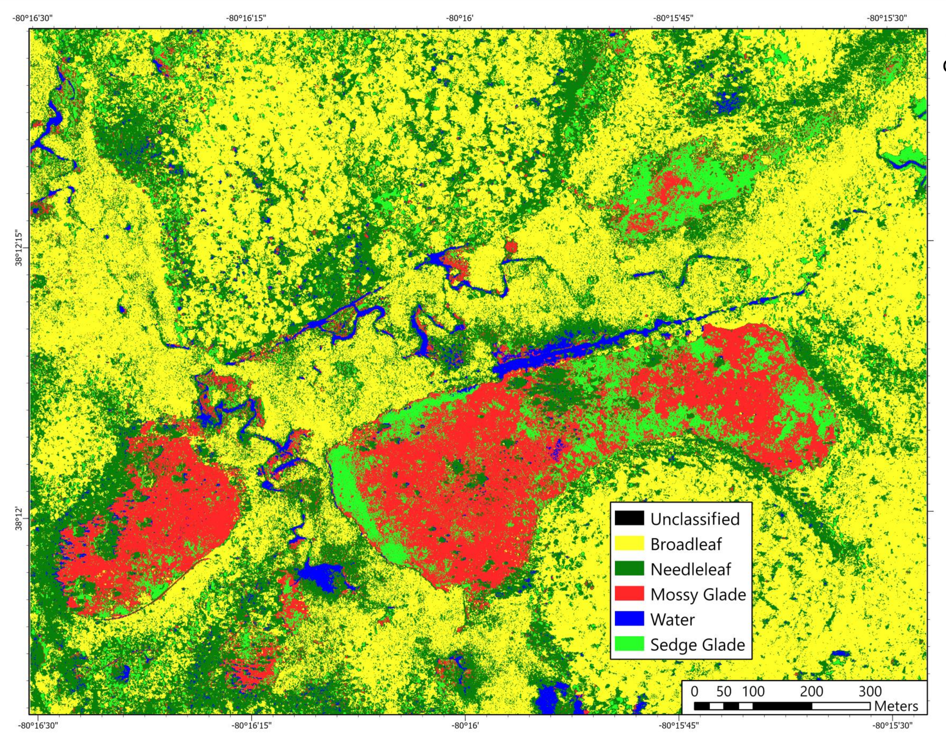
Methods



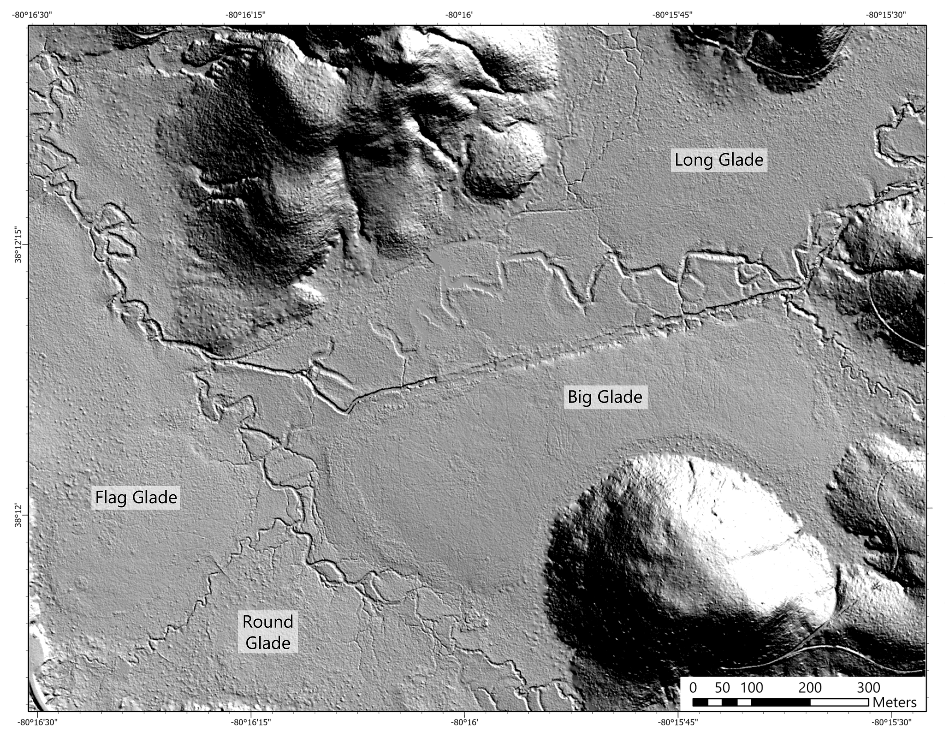
1. Aerial orthophoto visible channels
July 2018, NAIP

RGB imagery provides an intuitive "natural" view of the scene. Hue and shadow differentiate this scene's green forests, golden glades, white boardwalks, and brown waters. However, leaf-off imagery would offer better penetration of deciduous canopy and also convey a better sense of evergreen plant distribution. RGB midsummer views play only a supporting role due to the obscuring effect of aboveground vegetation and difficulty discerning between open water and mudflats.



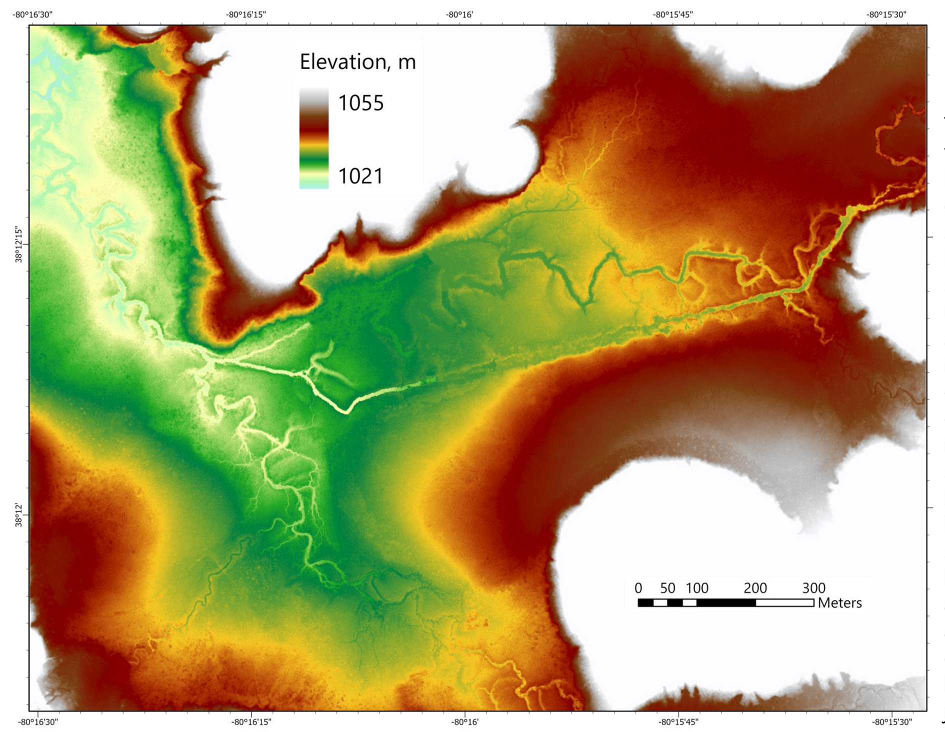
4. Landcover classes
derived from NAIP (Fig. 1)

Classification–here supervised Maximum Likelihood–invoking a near infrared channel can better differentiate between open water and adjacent terrestrial surfaces, due to the former's greater absorption of NIR radiation. This analysis detects beaver impoundments while excluding free-flowing stretches, a happy accident in retrospect! Drawbacks include obscuring by overhanging vegetation, and misclassification of some shadows as water.



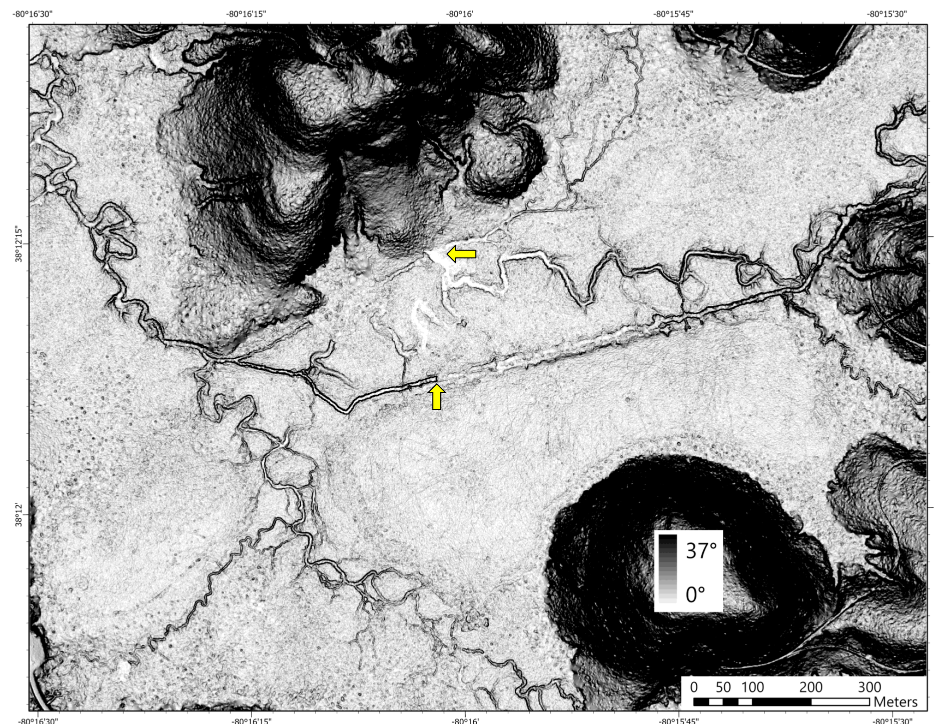
2. Hillshade
Dec. 2016, USGS Lidar-derived

Hillshade excels at display of comparative heights of waters versus the banks that contain them. This method, as with RGB imagery, fosters familiarity with the landscape's general character. Notice how the subtle doming of each glade is revealed. Drawbacks do abound though; for example, oversaturation on major hillslopes is the price of good floodplain illumination. Note also how the visibility of beaver dams and other linear features is reduced when aligned with the direction of illumination (azimuth and inclination of illumination are both 45°).



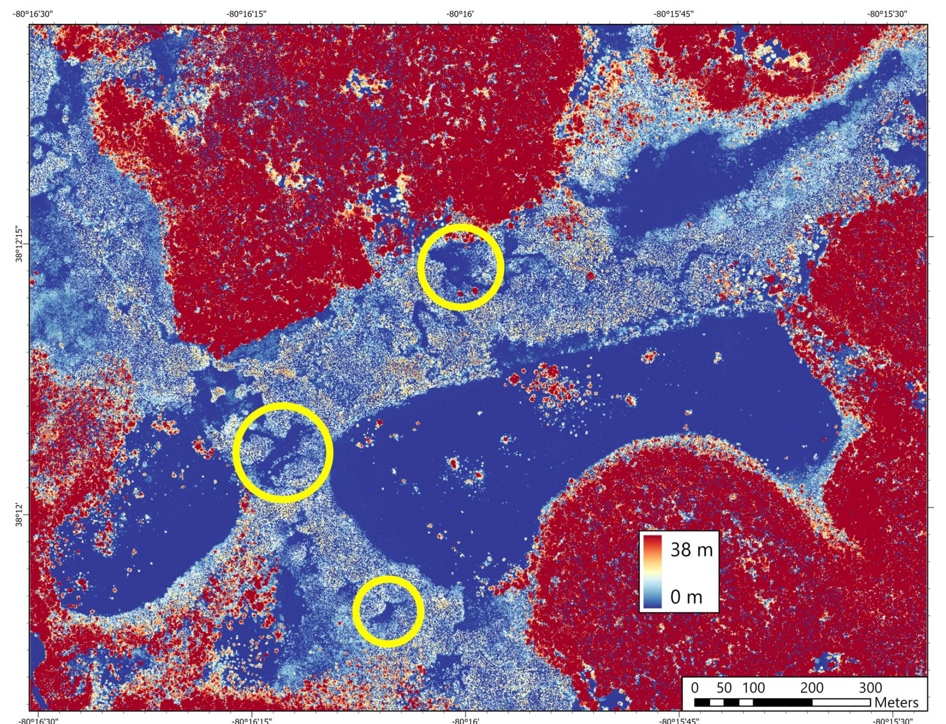
5. Bare-earth model
(BEM), Dec. 2016, USGS Lidar-derived

The BEM, derived directly from a ground-classified Lidar point cloud, allows derivation of hillshade, slope, and geomorphons. BEM is best by far at showing relative difference in elevations of water surfaces, each impoundment having its own characteristic elevation. Downsides include difficulty in scanning across the landscape: the demands of local terrain, elevation, and stream gradient must all be satisfied. When they are, a discontinuity appears along the profile of a stream, indicating a beaver dam or perhaps just a large fallen tree.



3. Slope, Dec. 2016, USGS Lidar-derived

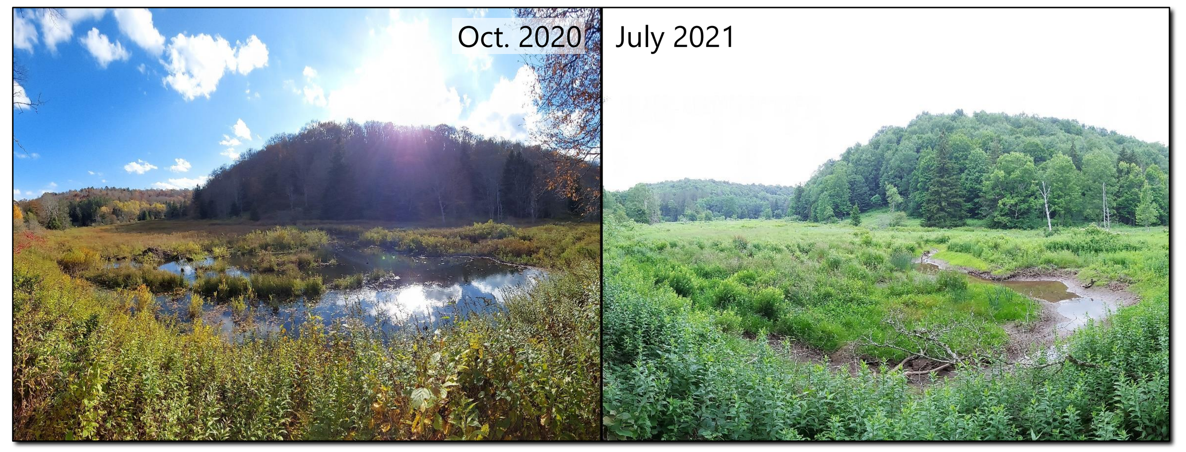
Surface slope analysis of the Glades best identifies incised stream channels and how they are capped by downstream faces of beaver dams. These edges stand in contrast with adjacent water surfaces (see arrows). As with geomorphon analysis (section at right), one can exploit dataset absences to valuable effect: extra textural contrast between water bodies and surroundings. This effect owes to sparseness of the Lidar point cloud at water surfaces, which become smoothly interpolated during generation of the bare-earth model (BEM) used for slope mapping.



6. Canopy Height Model, Dec. 2016, USGS Lidar-derived

CHM conveys a rough sense of the canopy's volume per unit area. CHM in the Glades cleaves into three main classes: low open-glade vegetation (deep blue), beaver-haunted shrub ecotone (pale hues), and mixed forest (red). Deep blue enclosures (yellow circles) along shrub belts indicate waterlogged areas, most likely tracing recent impoundment. CHM, derived from the above-ground-classified Lidar point cloud, has a larger vertical uncertainty relative to BEM, since CHM is found by differencing BEM and Surface Height Model.

Site validation



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Repeat photography reveals the dynamism of Glades hydrology and vegetation. At left are a lodge and impoundment on Charles Creek. At right, a dam and its impoundment have reverted to stream in a setting impacted by heavy machinery.

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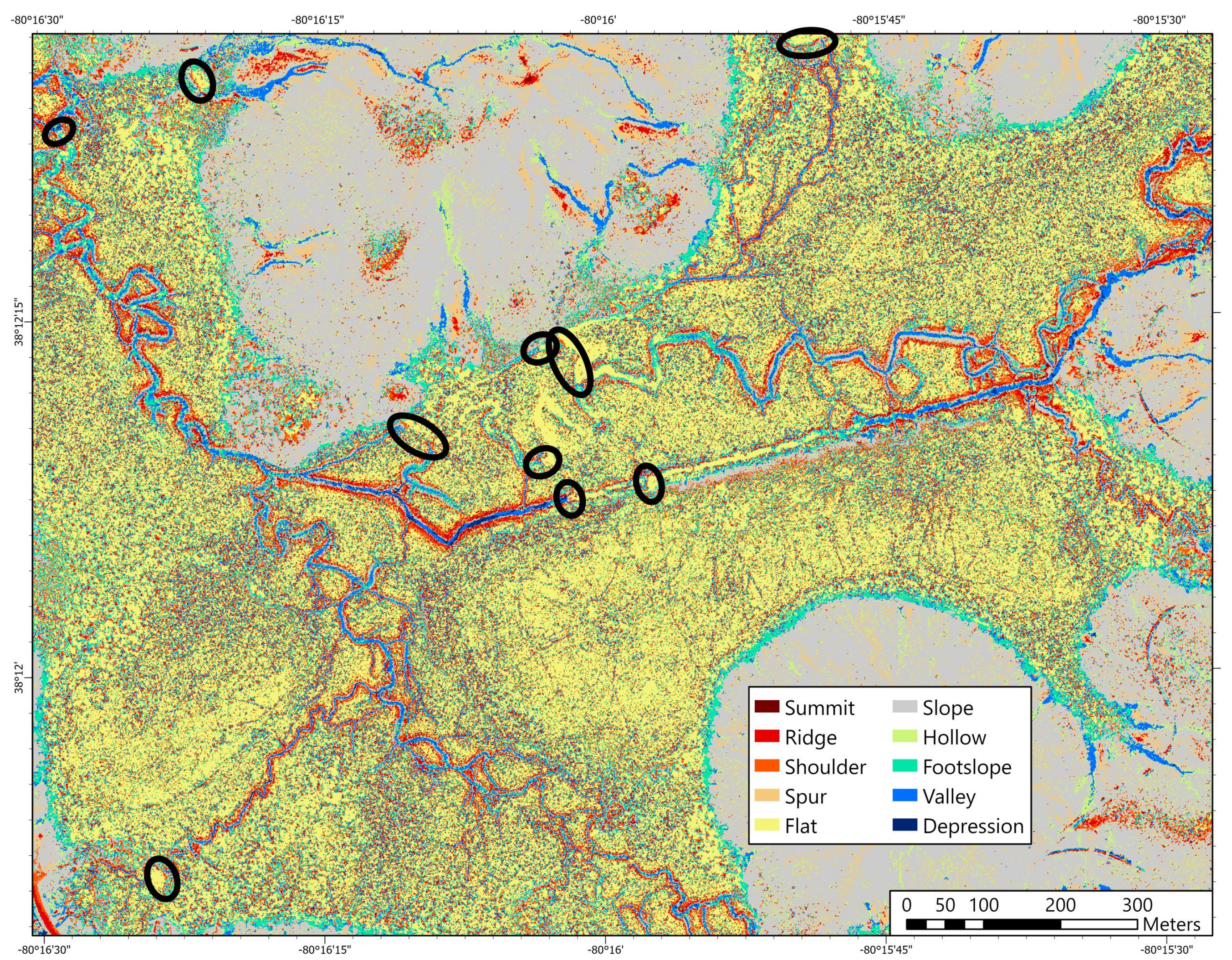
Key Findings: Geomorphon analysis brings a lot to the table



7. Geomorphon classification of Bare Earth Model (Fig. 5)

Ellipses on the map enclose beaver dams supporting active impoundments (in 2016), visible as noiseless Flat areas immediately upstream of each dam. This important feature of geomorphon-based impoundment detection is made possible by exploiting non-bathymetric Lidar's normally unfortunate tendency to fail at detecting laser returns from water surfaces. Note how these impoundments so starkly interrupt their host stream's vibrant Ridge-Valley-Ridge cross-sectional sequence. These features conspire to combinations of microtopographic texture that are well-suited to geomorphon visualization.

Comparison of Geomorphon (Fig. 7 above) performance vs. methods 1-6 (at left)

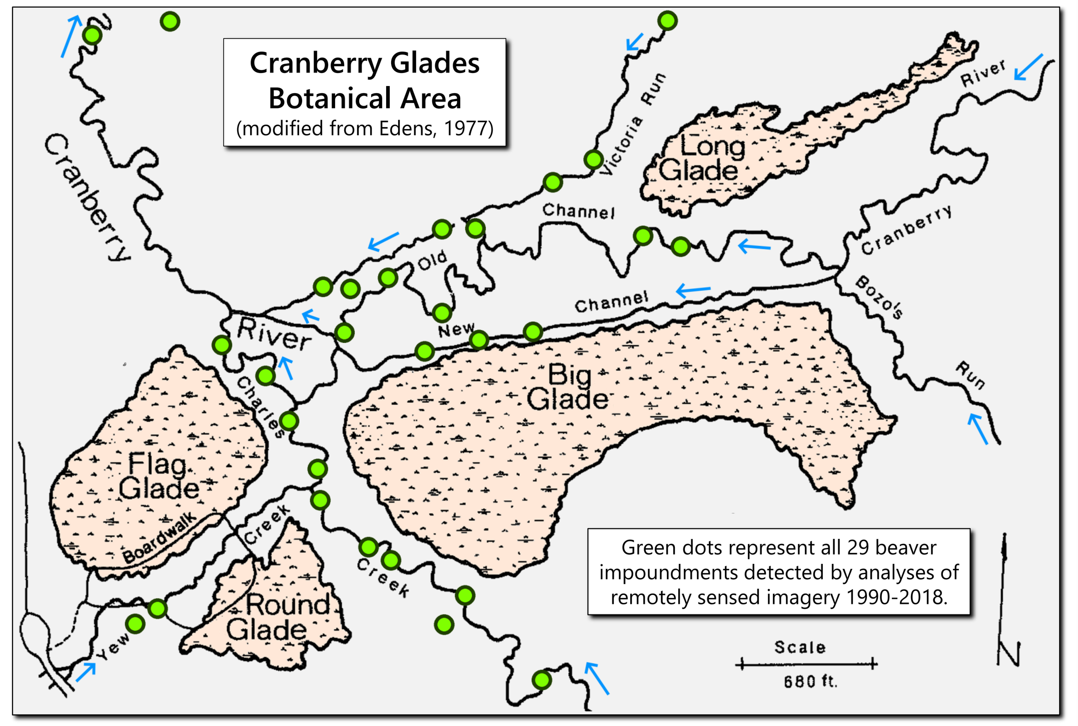
- ☀ Geomorphons successfully visualized all 10 impoundments (Fig. 7) that methods 1-6 managed to collectively detect from 2016 remotely sensed data.
- ☀ Invulnerable to the many drawbacks of illumination directionality that plague Hillshade interpretation.
- ☀ Best by far at highlighting the levees that bracket most of the major and secondary stream channels, and are in fact, quite unusual for a Central Appalachian peatland. Hillshade is runner-up.
- ☀ Reveals watertracks and game trails, which link glade interiors w/ interglade beaver complexes.
- ☀ Best at showing the zone in Big Glade, first noted by Darlington (1943) as being actively eroded during the early 1900s by Cranberry River. Runner-up: tie between Slope & Hillshade.
- ☀ Best captures relative landscape positions of most of the human transportation infrastructure. Examples include the road and boardwalk to the southwest. Trails to the east also reveal their cut-and-fill situations on hillslopes.
- ☀ Resilient to errors of interpolation that might otherwise require manual designation of breaklines along edges of water bodies.

Conclusions

Beaver have outsized roles as ecosystem engineers, making impacts that influence and intertwine with other key biophysical factors including climate change, local hydrological shifts, wildfires, and woody encroachment into imperiled peatlands such as Cranberry Glades. Monitoring of beaver activity, a potentially significant management tool for wetlands, may be best performed via remote sensing. Here we have produced the most complete reconstruction of recent beaver activity using a combination of Lidar, orthophotos, and repeat photography. Geomorphon analysis in particular has proven an effective tool for locating beaver impoundments within the matrix of shrubby peatland ecotone enmeshing the heart of Cranberry Glades Botanical Area. We identified 29 beaver impoundments from aerial data acquired between 1990 and 2018. The success of geomorphon analysis is ironically related to its exploitation of absences and errors in the Lidar data and intermediate Bare Earth Model from which it was derived. It is unclear whether these flaws-turned-features will remain useful when applied to datasets of higher quality.

Future work

- ☀ Broaden the spatiotemporal extent of analysis by scanning the entire Cranberry Glades bottomland and incorporating all relevant new and historical imagery.
- ☀ Include hyperspectral imagery to improve accuracy of land cover classifications.
- ☀ (Re)classify ground returns from Lidar point clouds using the Simple Morphological Filter (Pingel, 2013) to improve accuracy.
- ☀ Conduct more extensive field checks.
- ☀ Document beaver activity dynamics through time, e.g., changing numbers of impoundments per unit length of stream.



Green dots represent all 29 beaver impoundments detected by analyses of remotely sensed imagery 1990-2018.