Investigation into Hydrodynamics and Plant Communities of the Youghiogheny River Scour at Ohiopyle, Pennsylvania

This project was funded by a grant from The Nature Conservancy, and the data and recommendations are intended for use in the development of an Adaptive Management and Monitoring Plan for the Youghiogheny River Dam.

ON THE COVER
Youghiogheny River Scour
Photograph by: Christopher Tracey, Pennsylvania Natural Heritage Program

Investigation into Hydrodynamics and Plant Communities of the Youghiogheny River Scour at Ohiopyle, Pennsylvania

Final Report

Sustainable Rivers Program 2020

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Introduction

Riverscour communities that occur along the shores of swiftly flowing rivers in the Allegheny Mountains and Central Appalachian ecoregion are characterized by steep descents, swift to moderate currents, shallow to deep depths, and large cobble, boulder, or bedrock substrates. Often referred to as "Riverscour Prairies" by ecologists in the region, these sunny, open, riverside ecosystems dominated by large, warm-season grasses and species common in midwestern tallgrass prairie systems, these communities are maintained natural disturbances including high velocity floodwaters and ice-scour (Figure 1).

Figure 1. Ferncliff Scour, Ferncliff Natural Area (photo by Brad Georgic, PNHP).

Riverscour habitats form as material originating in the uplands, loosened by frost-heave and erosion, and carried by steep tributary streams during heavy rains, is deposited as the water slows when it enters the larger river. This material often accumulates just below the mouth of the tributary, forming a low, rocky area protruding into the river. These areas frequently flood and, if the river has enough energy, very few plant species are able to withstand the destructive power of those floods. Scour ecosystems are also found where rivers bend abruptly due to erosion-resistant bedrock. The scour process is especially severe when the debris washing over the habitat includes ice (Prowse & Culp 2003; Vanderhorst et al. 2010; Zimmerman 2011; Zimmerman et al. 2012; Vanderhorst 2017; Western Pennsylvania Conservancy 2018).

Because of the complexity of the microtopography and variation in water availability and substrate, sites described as riverscour communities support a high diversity of plant species. In particular, the riverscour communities in the Allegheny Mountains are particularly diverse. Many of the species of the Youghiogheny River Scour are native only in the southern to middle Appalachian Mountains. One of the most notable species of this ecosystem is Monongahela Barbara's Buttons (*Marshallia pulchra,* Figure 2) or more simply "*Marshallia*," a globally rare plant species (and candidate for federal listing) that grows in the tiny crevices between river scour boulders and bedrock ledges (Knapp et al. 2020). The Youghiogheny River, in southwestern Pennsylvania, for example, hosts the greatest concentration of globally at-risk plants of any area in Pennsylvania, as well as a large number of species of regional conservation concern (Western Pennsylvania Conservancy 2018). Many of the species of the Appalachian river scour reach their northern range limit in Southwestern Pennsylvania.

Development activities including transportation (railroads and highways) have substantially altered the natural hydrology of rivers throughout the Appalachian Mountain Region. Additionally, climate change impacts, specifically altered natural patterns of precipitation and temperature have undoubtedly impacted this ice scour and flood dependent ecosystem (Beltaos n.d.; Prowse & Culp 2003). Probably most significantly, construction of large reservoirs for hydroelectric power, drinking water, flood control, and recreation, have greatly modified natural flood and scour processes along rivers throughout the region.

As part of The Sustainable Rivers Program (SRP), a national partnership between The Nature Conservancy (TNC) and the U.S. Army Corps of Engineers (USACE), a team of ecologists from the Pennsylvania Natural Heritage Program, Powdermill Nature Reserve, USACE, and TNC conducted preliminary investigations into the hydrodynamics and vegetation patterns of the riverscour of the Youghiogheny River, downstream of the Youghiogheny River Dam at Confluence, Pennsylvania. These preliminary studies are the first step in developing a comprehensive adaptive ecological management plan to guide management of the Youghiogheny River Dam to ensure that ecological conditions that sustain the Youghiogheny River Scour are maintained.

Background

Figure 2. Marshallia pulchra (photo by Christopher Tracey, PNHP).

While it is generally accepted that hydrology and ice scour are the key factors in maintaining the habitat for riverside prairie species like *Marshallia*, questions still exist regarding the timing, duration, and severity of flood events and how river levels and the amount of water released from dams, such as the dam the Youghiogheny River, impact the plants, such as the *Marshallia*. Further, little baseline data exists to monitor ice and flood scour processes of the riverscour "prairies" on river shores of sandstone boulders and bedrock.

Local ecologists, who have been monitoring the riverscour habitats on the Youghiogheny for decades, have reported a decline in the *Marshallia* population indicated by decrease in area and number of individuals in each occurrence (Paul Wiegman, Steve Grund, and Charles Bier, personal communication). Herbivory, trampling by recreators, and invasion by exotic plants, such as Japanese knotweed (*Fallopia japonica*), have been suggested as playing a role in the decline. Changes to the flood-regime (duration, frequency, severity of flood events), changes in sediment deposition, and changes in the amount of winter ice and freeze-thaw processes are thought to be primary causes of the decline. Changes to the flood-regime are thought to impacts *Marshallia* and riverscour habitats in two ways:

1. A decline in the severity and frequency of flood and ice scour results in succession away from prairie-like floodplain openings favored by *Marshallia* and associates and towards closed floodplain shrubland and forest;
2. An increase in flood duration, or a more consistent duration may "flood-out" the Marshallia habitat resulting in erosion of fine sediments required by the species and its associates or drowning of the plants during critical times of the year.

Reports from PNHP, Ohiopyle State Park staff, local botanists, and initial inventory and reconnaissance by the authors of this report suggest that much of the area on the open scour of sites along the Youghiogheny is succeeding to a closed canopy condition while some of the area appears to be under water during the growing seasons. Visits by botanists familiar with Appalachian River Scour ecosystems during a recent conference of the Natural Areas Association in Pittsburgh (2019) also concluded that the riverscour community of the Youghiogheny River was less open than others in the region, especially those along the shores of un-dammed rivers.

To begin to understand the dynamics of the riverscour in the Youghiogheny, a plan was devised to determine specific hydrological patterns of five riverscour areas on the Youghiogheny River, downstream of the Youghiogheny River Dam (Figure 3), that support *Marshallia* and propose a strategy to monitor the flooding, ice scour, and vegetation, including establishing a baseline census of Marshallia within each site. We will use the information from these five sites to generalize potential inundation and other hydrological effects at other riverscours on the Youghiogheny.

To investigate this on a small scale and to test our ability to assess and monitor these processes, our team, which includes staff from TNC and Western Pennsylvania Conservancy (WPC) conducted a pilot research study on the Youghiogheny River in Pennsylvania within five known riverscour habitats supporting *Marshallia* and other riverscour plant species. This report details the specific methods and findings from this project from April to December 2020. Additionally, PNHP is assessing the populations of *Marshallia* through a USFWS Section 6 grant to collect data needed to develop a recovery plan for the species. In this effort, PNHP conducted a detailed baseline survey of all riverscour habitats where Marshallia was known and assessed the ecological condition of these sites on the Youghiogheny River.

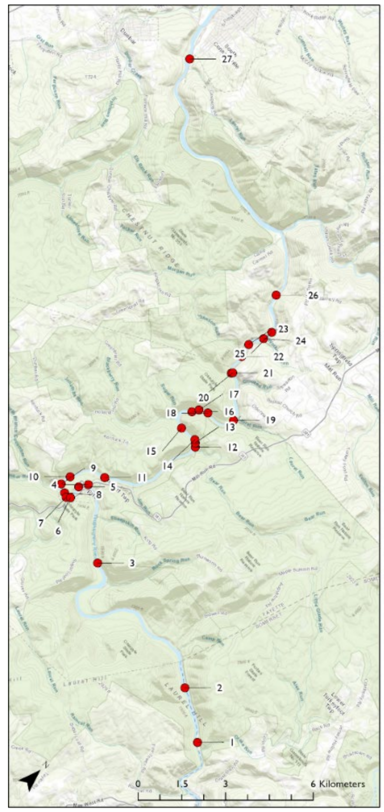
Ultimately, in keeping with the scope and goals of the SRP, the data collected in the monitoring study will be used to recommend modifications to discharge rates and timing of water releases from the Youghiogheny River Dam to improve condition for the *Marshallia* and other plant species of the riverscour.

Methods

Site Selection

Our study area was the Youghiogheny River Gorge downstream of the Confluence Dam and upstream of the town of Connellsville. PNHP has mapped 26 riverscours along the river (Figure 3), 18 of which support occurrences of *Marshallia*. We selected five target riverscour areas from the mapped riverscours that support *Marshallia* and other riverscour species. The five sites are:

- Drake Run – Ohiopyle State Park/State Game Lands #271. This site was selected as it is the most upstream riverscour prairie in the study area.
- Dimple Rock – Ohiopyle State Park Bear Run Nature Reserve
- Double Hydraulic – Ohiopyle State Park
- Ferncliff Peninsula – Ohiopyle State Park
- Meadow Run Ledges – Ohiopyle State Park



Name	MapNumber
Drake Run Cobble	1
Victoria Cobble. Victoria Ledges	3
Ohiopyle Falls	5
Ferncliff Penisula - End	8
High Trestle	11
Dimple Rock Rapids	12
Double Hydraulics	16
Bruner Run Left	21
Johnson Run	22
Connellsville Beach	27
Meadow Run Ledges	7
Cucumber Falls Cobble	9
Bidwell Island	2
Ferncliff Penisula - Base	4
Above Meadow Run Scour	6
Camel and Walrus	10
Swimmers Left	13
Swimmers Right	14
Bottle of Wine	15
River's End	17
Schoolhouse	18
Stairstep	19
Bruner Run Right	20
Pipeline Scour	23
Workman Island	24
Workman Scour	25
Above Camp Carmel Scour	26

Figure 3. Site location map

Site Mapping

Each site was mapped sites using a combination of aerial imagery, drone imagery, LiDAR, and field survey.

We developed generalized boundaries for each riverscour site by reviewing existing mapping for rare species in the PNHP databases against current aerial imagery. Each site was given a standardized name.

We collected high resolution aerial imagery via a drone flight on 2020-06-01 (Figure 4). Flight plans for the DJI Phantom 4 Pro drone were created inside Maps Made Easy on the Apple iPad. Flight altitude was 200 feet and used the Terrain Aware function to maintain the same 200 feet above the earth surface over the course of the flight path. Overlap of the flight paths was 80% between track and 80% along the track. All sites were flow except for Drake Run due to limited launch/recovery sites and high shrub cover that had already leafed out during our early June flight time.

Figure 4. Prepping the drone for flight (photo by PNHP).

Images were processed in ESRI's Drone2Map with assistance from James Whitacre from Powdermill Nature Reserve. Precise Digital Elevation Models (DEMs) were crated from the drone imagery and compared to DEMs created from publicly available 2007 PA Map LiDAR imagery. Resolution of these DEMs are 25 cm (0.8 ft). Complete documentation of the methods can be found in Appendix A – Elevation Processing Methods .

These high resolution DEMs were delivered to the USACE for integration into the HEC-RAS model.

Additionally, we made additional observations of on the ground conditions that may be useful for understanding the site conditions (e.g. wrack lines, high water marks) and collected GPS points.

Vegetation Assessment Methods

Plant Community Classification Plots

Within each riverscour site, we established 100m^2 quantitative community classification plots within the specific floodplain scour zone that supported the *Marshallia*. Sampling plots followed quantitative community sampling protocols developed by NatureServe for describing and classifying plant community associations ((Sneddon 1998; Strakosch-Walz 2000; Ecological Society of America 2004)). We established plots non-randomly to be representative of the community zone (Ellenberg & Mueller-Dombois 1974). When site conditions did not allow for square plot configurations, we used rectangular plots to meet the 100m2 standard area as specified for shrub and herbaceous communities. We sampled each plot once in late-June 2020 in order to capture the most species possible during the growing season.

We used estimated cover values based on the Braun-Blanquet method to record the cover of each vascular and non-vascular plant species within the plot by strata. We used the following strata: "canopy" for trees > 5m in height, "tall shrub" for woody plants 2 – 5m in height, "short shrub" for woody plants 0.5 - 2m in height, "herbaceous" for herbaceous vegetation and very short woody plants. We identified all vascular plants to species and bryophytes to genus (an attempt was made to identify all plants to species). Any plants that could not be positively identified in the field were collected for later identification. We deposited all collected specimens at the herbarium of the Carnegie Museum of Natural History in Pittsburgh. We evaluated substrate type, soil drainage, topographic position, and hydrologic regime site as part of the standard data collection procedure.

We record environmental data, including hydrologic descriptors, aspect, elevation, slope, landform, Cowardin system (Cowardin 1979), and topographic position in the field. Other data, including surficial geology, stand size, distance to river center, and ecoregion were determined in GIS. For soil assessment, we excavated and described soil that had accumulated in crevices and between cobble/boulders and recorded sample depth, texture, field pH, color, stoniness, and depth of organic soil. For each study site, we developed a written description for each site, which included an ecological overview and information detailing whether the plot was representative of the community as a whole, the overall environmental condition of the plot, and its landscape context.

In all, we established a total of six plots within monitoring sites on riverscours along the Youghiogheny River. A sample plot data collection form is included in the Appendix B.

Line-Intercept Transects

We used a line-intercept method, a rapid, accurate method for quantifying vegetation and substrate conditions across a gradient, to quantify the percent cover of plant species and substrate within the riverscour. Depending on the size and heterogeneity of the site, we established either one or two transects through each riverscour site, originating at the upland transition and ending at the water. We established transects perpendicularly to the river, and usually represented the widest portion of the riverscour. We sampled the transects in June in order to capture the most species possible during the growing season.

Figure 5. Marshallia pulchra along the line-intercept transect (photo by Christopher Tracey, PNHP).

We marked each transect using a 50m marking tape, pulled taught, and laid flat along the riverscour surface (Figure 5). We recorded the origin and end of each transect with a GPS and recorded the azimuth of the transect line on the data sheet. We also recorded the length of the transect line and slope. We marked the origin with a marking flag. We compiled a brief environmental description for each transect and photographed the transect origin and end points.

With each one m section, we recorded the number of centimeters occupied/intercepted by the line for each species. We also recorded ground cover, including total cover of non-vascular species.

Marshallia census

Following standard Natural Heritage Program methodology to document plant populations (Appendix C), PNHP botanists conducted detailed mapping and assessment of the *Marshallia* in conjunction with a USFWS Section 6 grant to the PA Department of Conservation and Natural Resources. Following mapping of the entire subpopulations at the five sites, PNHP botanists counted all plants and mapped individual clumps on site maps created from high resolution aerial imagery at three of the five sites. In 2020, botanists conducted a *Marshallia* census at Meadow Run, Double Hydraulic, and Dimple Rock (plus additional sites not included in this study); Ferncliff and Drake Run will be assessed in subsequent years. Botanists recorded the number of individuals in each clump and the number of flowers were per individual was recorded. Botanists recorded substrate, soil moisture, and competing vegetation, and estimated the overall condition of each sub-population.

Using these data, we created a GIS layer of polygons that represent the *Marshallia* habitat at the five riverscour sites. In GIS, we investigated the impact of various inundation scenarios and estimate inundation patterns using HEC-RAS.

Hydrological Assessment Methods

Hydrological Modeling

Hydrologists from the USACE created a hydrologic model in HEC-RAS 5.0.7 using stream geometry was based on the USACE Pittsburgh District CWMS RAS model. Cross sections upstream of Connellsville were used. Based on visual inspection of aerial imagery, simplified bathymetry was assumed by reducing the cross section elevation in locations where the water surface was captured by the LiDAR. Downstream boundary condition is the USGS rating curve at the Connellsville gage. Terrain input was initially based on PA Map LiDAR.

USACE estimated flows for each of the three riverscour sites at a time period when the delineated *Marshallia* habitat was approximately 50% inundated. Then they used Ohiopyle gage data from between 2014 and 2020 to calculate the percent of the time each habitat area has been inundated by month.

An inspection of the results from the initial model showed that the model may need improvement, especially at the Double Hydraulic site, where the *Marshallia* habitat was inundated during almost all flows (>99% of the time). This showed the need to improve the model. We used the improved drone-derived digital surface models as an overlay in the HEC-RAS model which improved the inundation frequency estimates. Drake Run is still using LiDAR as UAV imagery was not available.

Hydrograph

We obtained data for the Youghiogheny River for the past 12 months as well as the 10-year mean from the USGS gauging station (USGS 03081500 Youghiogheny River at Ohiopyle, PA) located just downstream of the main waterfall (39.870833N, 79.493056W). We also obtained data for the gage at Confluence (USGS 03081000 Youghiogheny River below Confluence, PA) just upstream of the Drake Run scour, however, as the data is somewhat correlated to the Ohiopyle gage, all subsequent analyses have used the Ohiopyle gage.

Field Cameras

We installed field cameras (Figure 6) to capture flood images and synced these images with river hydrograph data to figure out the pattern of inundation during the grant period and determine how changes in flow may affect these small and topographically complex sites.

We chose the Bushnell "Core DS Low Glow" trail cameras as they had the ability to capture individual photos at 15 minute intervals. Cameras were placed in custom fitted steel security cases and secured to trees with a steel cable lock. Camera were typically placed 1.3 – 2.4 meters above the ground surface. Wherever possible we adjusted the cameras to point downward towards the riverscour.

Cameras were installed at four of the five study sites—cameras were not currently deployed at Meadow Run due to potential tampering by park visitors. The cameras at Dimple Rock, Double Hydraulic and the Ferncliff – End sites were deployed on 2020-05-11; whereas Drake Run was deployed on 2020-05-20. Camera locations were GPS mapped and approximate field of view is indicated on the site maps.

Cameras were initially set to record images at 15 minute intervals. Camera resolution was initially set to 8MP.

Figure 6. Field camera installed at the Ferncliff end riverscour (photo by PNHP).

Recording generally occurred over a 24 hour period. This was changed as the season progressed due to memory and battery issues.

An approximately two-foot high steel staff gage (Forestry Suppliers 0-2.06' WaterMark Style "C" Stream Gauge) was placed at six of the camera locations (Ferncliff 2 and Dimple Rock 1 did not have staff gages placed due to limited attachment opportunities). This was fastened trees within the cameras field of view with steel wire. The base of the staff gage was typically even with the ground surface.

These field cameras were maintained throughout the year, from May through September. In all, there were 22 camera check visits across the four sites, over 10 field days. These checks have typically been spaced 4-6 weeks apart (Table 1). Note that the field cameras have continued to have been maintained past the period outlined in this report.

Table 1. Summary of field camera deployment dates and check visits. A "D" indicates the day the camera was deployed.

		Visit Date									
Site	**Camera**	**5/11**	**5/20**	**6/1**	**6/11**	**6/24**	**6/25**	**7/29**	**8/8**	**9/1**	**9/25**
Dimple	1	D		X		X		X		X	X
Rock	2	D		X		X		X		X	X
Double	1	D	X	X			X	X		X	
Hydraulic	2	D	X	X			X	X		X	
Drake	1		D		X				X		X
Run	2		D		X				X		X
Ferncliff	1	D	X	X		X		X		X	
End	2	D	X	X		X		X		X	

We developed a method to overlay a hydrograph over each image and create an animated video. We developed a custom script in R (R Core Team 2020) in that downloads instantaneous flow data using the dataRetrieval package (DeCicco et al. 2020) and links in to each camera image timestamp using the exifr package (Dunnington & Harvey 2019). The R code to create these videos is available at https://github.com/PNHP/timelapse_hydro.

Results and Discussion

Low precipitation in the region during the 2020 season resulted in a lower than normal river flows on the Youghiogheny as indicated on the hydrograph (Figure 7) as compared to the mean and range over the past decade (2010-2020). Small spikes in the gauging data above base-flow between Mid-June to Mid-September coincide with weekend releases of water from the Youghiogheny River Dam to support kayaking and rafting. In general, river levels were considerably lower than the average for the summer months in 2020 and at the very low end of the range.

Images captured open, dry conditions throughout the growing season for the areas within the field of view supporting *Marshallia*. Cameras did not record inundation at any site until November, when the Ohiopyle gauge recorded flows of over 1,100 cfs.

Field cameras also recorded the site use by sunbathers and swimmers as well as animal use of the scour. The impact of recreation on the scour habitat was most evident at the Meadow Run Ledges, which is an easily accessible, mostly bedrock, "beach-like" area where sunbathers and swimmers congregated throughout the summer months. Trampling is most-likely impacting the *Marshallia* and other plants at this site. One of the cameras at Ferncliff peninsula captured an occasional off-trail hiker, but trampling is probably not a major issue at the other sites given their relative inaccessibility. The open area of the scour at Dimple Rock is used as a portage around difficult rapids, but the main portage route was outside the field of view of camera at that site. While the cameras did capture an occasional deer foraging in the scour, deer damage to *Marshallia* was not evident in the field and there was no indication that deer congregated in any place on the scour. However, we did not formally review the camera footage in its entirety.

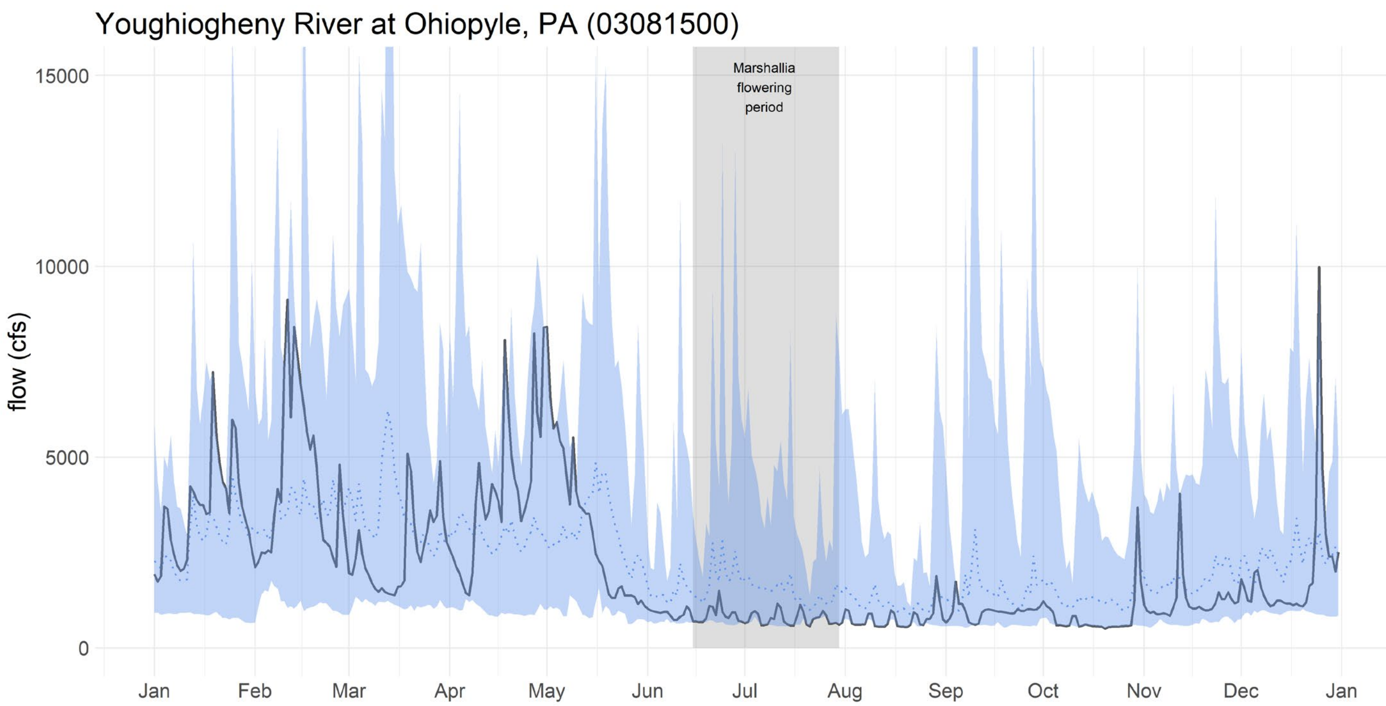


Figure 7. Streamflow at the Youghiogheny River at Ohiopyle gage (dark blue = 2020 flow, dotted blue = mean, light blue = range) from January 2020 to December 2020. The gray shaded bar represents the typical flowering period for *Marshallia pulchra*.

Site Mapping Results

From aerial imagery obtained in this project, the mapped riverscour area ranged from 4,705 m^2 at Double Hydraulic to 26,134 m^2 at Drake Run. Elevations ranged from 1044.5 m Double Hydraulic to 1286.7m at Drake Run. Aspects were, on average, South to Southwest-facing (Table 2). The size of *Marshallia* populations ranged from 1,178 m^2 at Drake Run to 37 m^2 at Dimple Rock. Maps for each individual site are presented below.

Table 2. Landscape variables obtained from GIS data and aerial imagery interpretation.

	Mean Slope (°)	**Mean Aspect (°)**	**Mean Elevation (m)**	**Size (m)**	**Size of *Marshallia* population (m²)**	**Number *Marshallia* clumps**
Dimple Rock	7.0	223.0	1076,2	5,115	37	~10
Double Hydraulic	7.5	189.6	1044.5	4,705	115	24
Drake Run	5.9	242.7	1286.7	26,134	1,178	~110
Ferncliff End	6.6	186.2	1163.7	20,459	528	unknown
Meadow Run	5.7	247.0	1165.6	7,185	578	475

Generally speaking, we found the drone imagery to be far superior to other available imagery for the sites with increased resolution and detail (Figure 8).

Figure 8. Comparison of previously available imagery (left) at Meadow Run to the imagery captured by our UAV work (right). The orange line indicates the transect used to develop the profile graph in Figure 9.

Elevation in the drone derived digital surface model for Meadow Run, differed from the LiDAR derived DEM a range of -4.42 m to 4.88 m (mean = 0.49 m). Figure 9 shows a comparison of the elevation as mapped in the 2007 PA Map LiDAR data to a digital terrain dataset generated through a drone flight. The increase in elevation in the drone imagery between the 5 and 20 m distances better represents the rock outcropping, however, it may be an over estimate due to the presence of a tree canopy. The presence of a large bolder in the channel of the Youghiogheny can be seen between the 50 and 60 m distances.

Note that our digital surface models were generated from drone imagery that was take on June 1, 2020, which was after leaf-out and thus at some sites are likely not true representations of the scour surface. We recommend using aerial imagery taken earlier in the season (or in late fall).

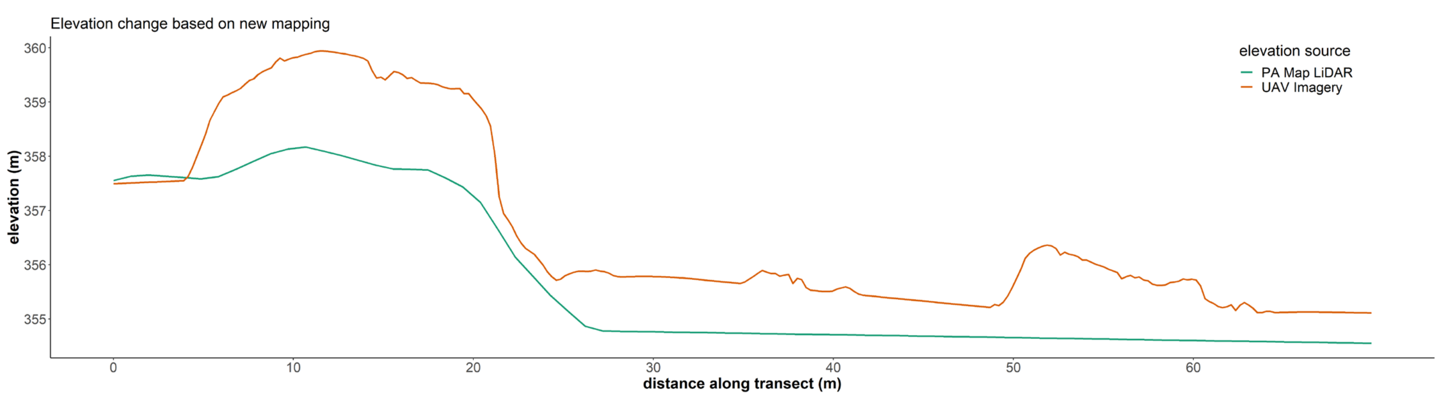


Figure 9. Change in the elevation along a sample transect between the PA Map and UAV mission elevation datasets. See Figure 7 for the location of the transect.

Descriptions and site maps for the five focal sites are presented in the following subsections.

Drake Run

This site sits along the edge of Ohiopyle State Park on the border of State Game Lands #271. Drake Run is an interesting riverscour as the Marshallia is at the far downstream end of scour. Compared to other sites on the Youghiogheny, this site is very shrubby (Figures 10 and 11). We suspect that this site has less scouring by coarse woody debris and/or ice sheets due to its proximity to the dam and thus a limited run of the river to provide these inputs. There is a small patch of open riverscour habitat upstream of the *Marshallia* patch that supports some riverscour species (e.g. *Ionactis linearifolia*), but *Marshallia*, itself is not present there.

Our estimates of the *Marshallia* population at Drake Run is approximately 110 clumps. We did not record more detailed data about this population during this field season.

Figure 10. The edge of the scour habitat at Drake Run. Royal fern is present along the edge of scour where higher velocity and more frequent inundation occurs (photo by PNHP).

Figure 11. Map of Drake Run showing the extent of the Marshallia population, camera locations, approximate camera field of view, and vegetation transects.

Dimple Rock

Where Bear Run empties into the Youghiogheny River is a dangerously famous set of rapids known as Dimple Rock, named for a large boulder that lies in the main channel of the river (Figures 12 and 13). This site is a considerable sand and cobble fan formed by Bear Run on river right with Ohiopyle State Park along its border with the Bear Run Nature Reserve. When the Youghiogheny floods, it passes through channels in the boulder fan roughly perpendicular to the channels of Bear Run. *Marshallia* is surprisingly not on the main cobble scour, but rather between large boulders downstream of the site. It is unclear if *Marshallia* ever occurred on the large riverscour. Our 2020 count of the *Marshallia* population is 24 plants with 20 flowering stems. This is a small colony, and we counted fewer clumps than in 2001, but the difference is not large enough to conclude that there is a downward trend.

Figure 12. The large scour prairie at the mouth of Bear Run (photo by PNHP).

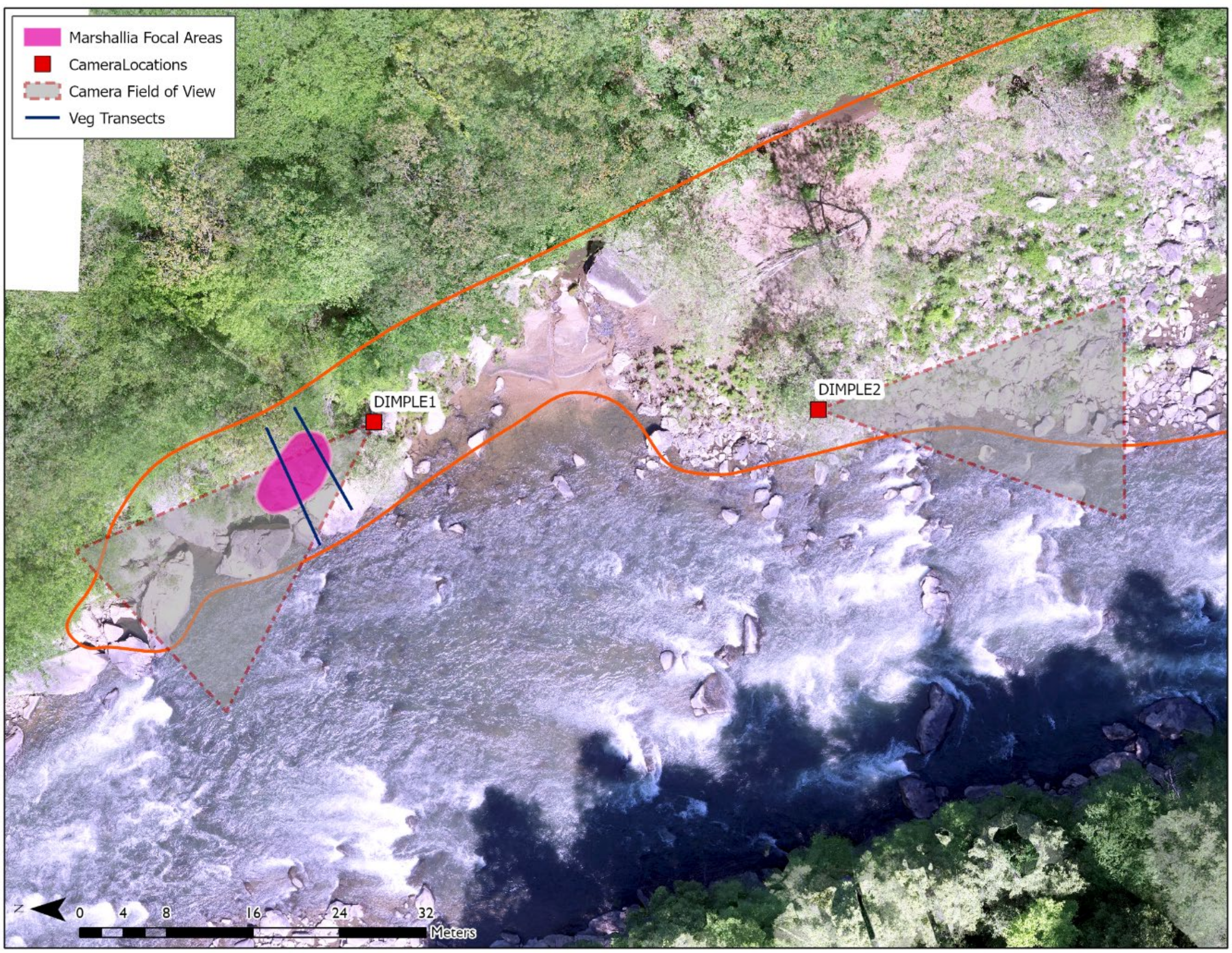


Figure 13. Map of Dimple Rock showing the extent of the Marshallia population, camera locations, approximate camera field of view, and vegetation transects.

Double Hydraulic

Just downstream of the Dimple Rock site, is the Double Hydraulic riverscour. Large boulders that armor the site (Figures 14 and 15) along the river side of the riverscour. This does appear to provide some shelter from intense scour events which has favored the growth of several large sycamores. Looking at water flow patterns on the site, water may enter the riverscour from the backside of the riverscour and flow across the site. This site is entirely contained within Ohiopyle State Park. Although this riverscour appears to be fairly large, much of the downstream is different. Double Hydraulic is an interesting site as it is somewhat armored by large boulders along the main river channel. Examination of the topography and drainage patterns along the site indicate that much of the water that inundates the site during high flows enters from the upstream edge of the site and drains in a channel on the backside of the large boulders.

Figure 14. Looking south across the Double Hydraulic scour. Note the large boulders that shelter scour area (photo by PNHP).

Our estimates of the *Marshallia* population at Double Hydraulic is 28 clumps, 114 rosettes, and 67 culms. This number is slightly higher than recent estimates, due to the discovery of additional plants downstream.

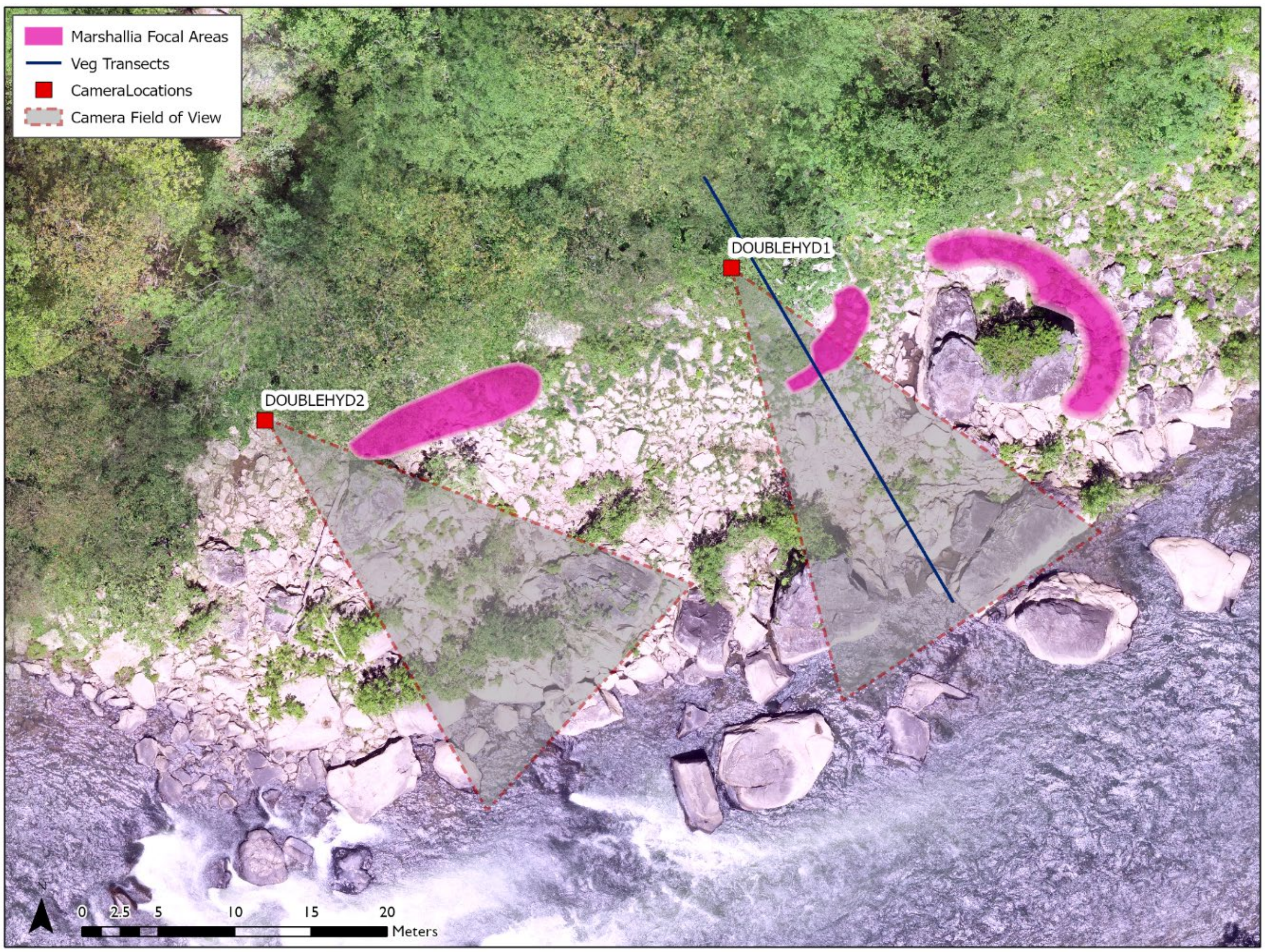


Figure 15. Map of Double Hydraulic showing the extent of the Marshallia population, camera locations, approximate camera field of view, and vegetation transects.

Ferncliff Peninsula

The Ferncliff Peninsula Natural Area within Ohiopyle State Park supports some of the highest-quality riverscour habitat in the region. The main scour at Ferncliff is at the tip of the peninsula on the inside of the nearly 180 degree sweeping bend in the Youghiogheny River, directly across from the Meadow Run riverscour (see below). Most if not all of the riverscours on the Youghiogheny are on the outside bends of the river, associated with higher velocity and sheer stress, making this site interesting from hydrological perspective. The riverscour itself is a large expanse of boulders, cobble, gravel, and sand (Figures 16 and 17). Many trees are present compared to other riverscours, potentially indicating its experiencing of less sheer stress. Large riffles and rapids are present in the stream. This area probably gets washed over repeatedly during spring floods, as there is a flood channel behind the habitat. We did not take a formal estimate of the *Marshallia* population at Ferncliff Peninsula this season. Twenty-four flowering stems were noted within our plot/transect area within the field of view of the FERNCLIFF1 camera.

Figure 16. A large river scour prairie at the end of the Ferncliff peninsula (photo by PNHP).

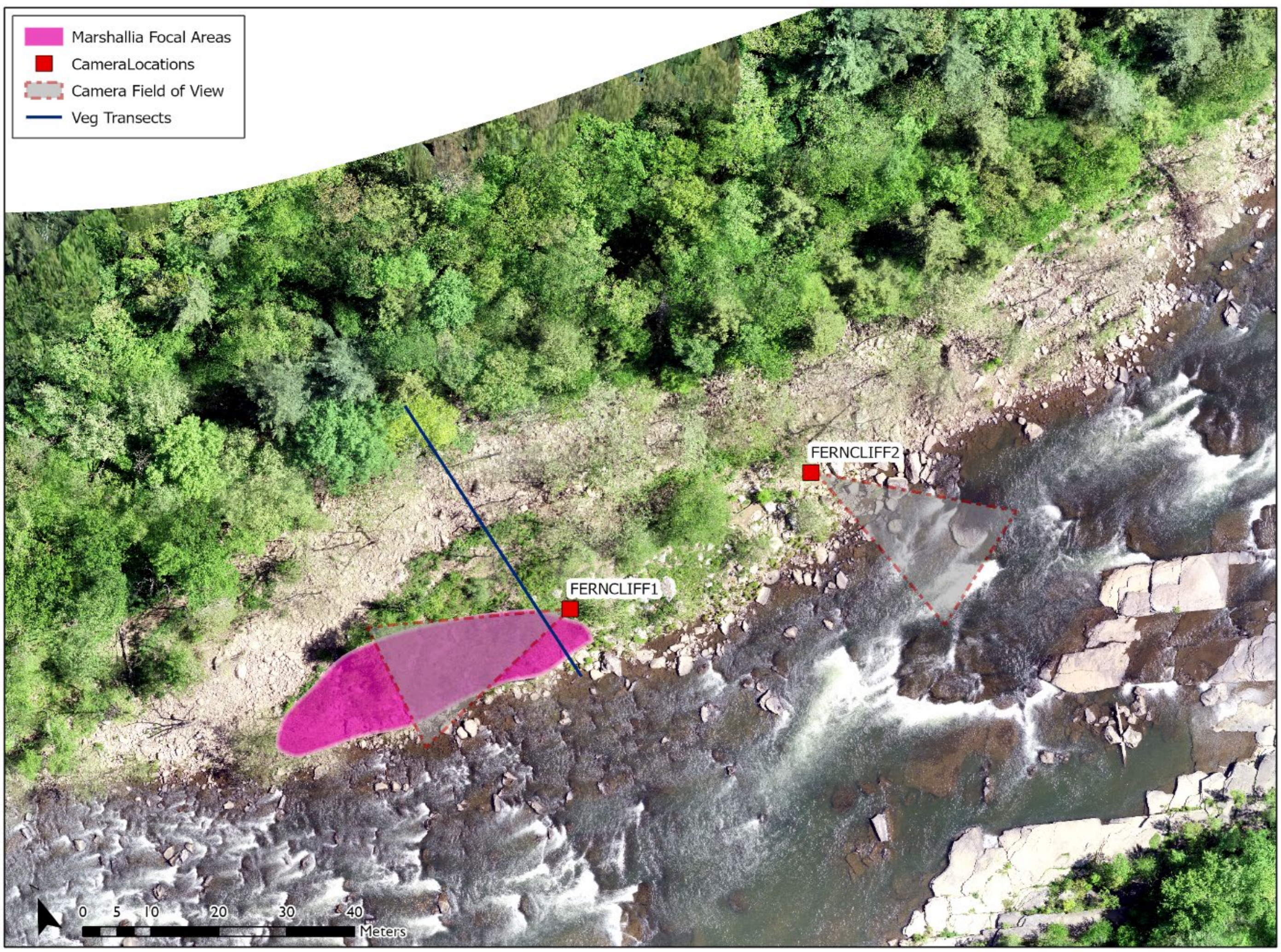


Figure 17. Map of Ferncliff Peninsula End showing the extent of the Marshallia population, camera locations, approximate camera field of view, and vegetation transects.

Meadow Run Ledges

Figure 18. Meadow Run Ledges (photo by PNHP).

This site is located directly across the river from the Ferncliff Peninsula – End site. It is also within Ohiopyle State Park. Unlike most of the other riverscours we studied, this site is composed of an exposed series of bedrock shelves or ledges alongside the outside bend of the river. These ledges have large exposed surfaces with clumps of vegetation (Figures 18 and 19). The peat and sand filled crevices of the sandstone pavement support populations of *M. pulchra* and other riverscour species. This is especially observable at the bases of vertical rises separating adjacent horizontal surfaces. Annual spring floods keep the area well scoured. A blazed trail for hikers bisects the site. The site is also popular for fishing, sunbathing, and swimming. Trampling of the riverscour species may be an issue, but the crevice microhabitat is in some cases protective, and riverscour species can presumably take some of that sort of disturbance. Our estimates of the *Marshallia* population here 475 clumps, 2,113 rosettes, 347 culms 215 clumps. As noted by PNHP Botanists, this site is likely the best locality for *Marshallia* in Pennsylvania.

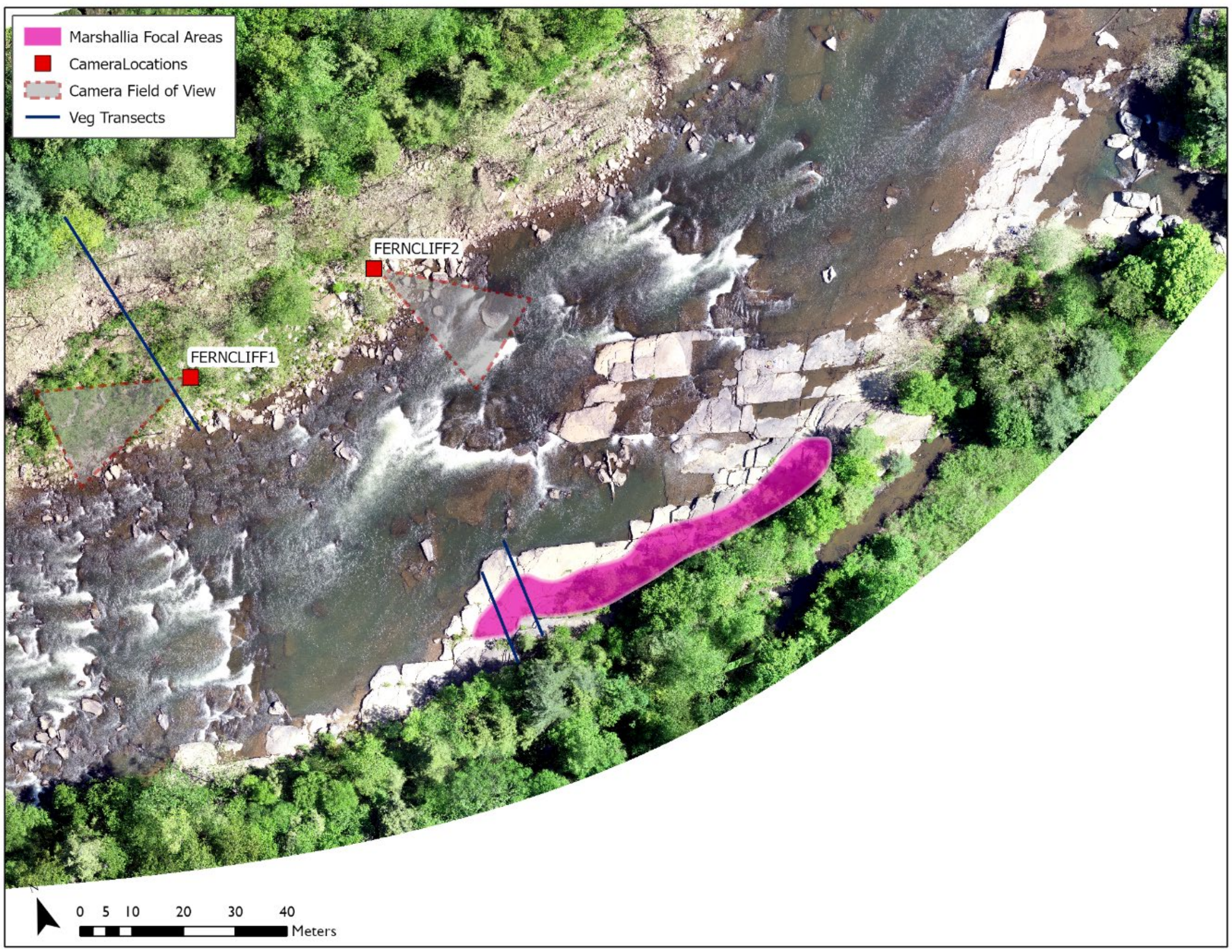


Figure 19. Map of Meadow Run Ledges showing the extent of the Marshallia population, camera locations, approximate camera field of view, and vegetation transects.

Plant Community Assessment

The Youghiogheny River scour supports several different plant communities associated with rapidly flowing water, narrow gorges, and outcrops of bedrock and boulders characteristic of rocky river shores of the Allegheny Mountains. Floodplain wetlands communities include Sycamore Floodplain Forest, Mixed Hardwood Floodplain Thicket, and Floodplain Scour Community, along with several upland community types found on the steep walls of the gorge and coves formed by tributary streams. The Floodplain Scour Community of the Youghiogheny, which was the focus of this work, is described here: http://www.naturalheritage.state.pa.us/Community.aspx?=16011. The five scour sites downstream of the Youghiogheny River Dam in this study exhibited similar plant composition and ecological characteristics as described in the Pennsylvania community classification (Zimmerman & Podniesinski 2008; Zimmerman et al. 2012). The composition of vascular plant species, the geographic location of the community, hydrodynamic processes, and physical ecosystem variables documented for the Youghiogheny River are similar to those described by NatureServe in their description of the Appalachian Acidic Sandstone Rivershore Prairie ((*Betula nigra, Ilex verticillata) / Andropogon gerardii - Solidago simplex var. racemosa* Riverscour Wet Meadow: CEGL006623) (Vanderhorst et al. 2010; Vanderhorst 2017; NatureServe 2020). This community association is regarded as a G2 (Imperiled) by NatureServe and known from the Gauley, Tygart's Valley, Middle Fork, and Cheat rivers on the west slope of the Eastern Continental Divide in West Virginia (NatureServe 2020). NatureServe suggests that it "may also occur along the Youghiogheny River in Pennsylvania (NatureServe 2020). While we did not compare plot data statistically with plot data from these other rivers, the similarity in species composition and physical ecosystem variables suggests that the scour communities along the Youghiogheny are consistent with the description of the Appalachian Acidic Sandstone Rivershore Prairie (CEGL006623) and should be acknowledged by NatureServe as occurring in Pennsylvania.

The Appalachian Acidic Sandstone Rivershore Prairie is a patchwork of vegetated and sparsely vegetated zones, occurring in a repeating pattern at all sites we surveyed. From our preliminary investigation, it was clear that in addition to the large expanse of unvegetated bedrock and boulder, at least two vegetative zones were present within the sites. The first was a diverse "riverscour prairie" with an assortment of short shrubs, battered trees, and forbs, including *Marshallia*. The *Marshallia* was often associated with the following species – yellow star-grass (*Hypoxis hirsuta*), azure bluets (*Houstonia cerulea*), nodding onion (*Allium cernuum*), wood betony (*Pedicularis canadensis*), heart-leaved meadow parsnip (*Zizia aptera*), and arrow-leaved violet (*Viola sagittata*) and growing on shallow alluvial soil over bedrock and boulders, or nestled in the crevasses of the rock. The micro-sites supporting *Marshallia* and its associates were found scattered throughout the larger scour prairie. A second zone, dominated by royal fern (*Osmunda regalis*), was distinct from the rest of the riverscour prairie, often occupying the lowest elevations on the riverscour, often bordering the flowing water. This second zone had considerably fewer species than its diverse riverscour prairie neighbor, however, it was not present in a large enough area at every site to assess with a standard classification plot – usually existing in a narrow line, sometimes only one-to-two plants wide at the edge of flowing water. The *Marshallia* zone of the riverscour prairie had a mean species diversity of 58 (11.9 s.d.) species of vascular plants (Table 3). In contrast, in the one area of royal fern that was large enough to establish a plot (Double Hydraulic), there were only 24 species of vascular plants and 3 non-vascular taxa per $100m^2$. Emergent aquatic species, associated with floodplain wetlands such as water-willow (*Justicia americana*) was found intermixed with the royal fern. *Marshallia* was not present within the royal fern-dominated plot at Double Hydraulic, but royal fern was present at low levels in several plots among the five sites. There were often shrubby zones within the scour sites as well. Nine-bark (*Physocarpus opulifolius*), silky dogwood (*Cornus amomum*), winterberry holly (*Illex verticillata*), highbush blueberry (*Vaccinium corymbosum*), and swamp azalea (*Rhododendron viscosum*) were most often associated with the shrub zones, along with battered trees such as black-gum (*Nyssa sylvatica*) and sycamore (*Platanus occidentalis*). All of these species are associated with the Appalachian Acidic Rivershore Prairie (NatureServe 2020). Nonvascular plants, particularly Fontinalis spp. contributed between 1-25% of the ground cover. The royal fern zone at Double Hydraulic and the Meadow Run scour exhibited the lowest bryophyte cover, which appears to be related to with the percent cover of bedrock.

Table 3. Ecological characteristics documented in Natural Heritage Plots established at 5 sites in riverscour ecosystems on the Youghiogheny River.

		% Cover										
Site	**Plot**	**Royal Fern**	**Marshallia**	**Rock**	**Sand**	**Litter**	**Canopy**	**Tall Shrub**	**Short Shrub**	**Herb**	**Nonvascular**	**Vascular Species Richness**
Dimple Rock	1	<1	<1	65	25	0	15	35	15	30	10	46
Double Hydraulic	1	0	<1	37	1	1	0	3	7.5	88	13	55
	2*	63	0	80	10	0	0	30	3	60	1	24
Drake Run	1	0	<1	30	30	10	15	60	30	40	25	69
Ferncliff	1	3	<1	40	30	20	35	35	25	70	5	72
Meadow Run	1	<1		85	5	5	0	45	15	40	3	48

* Plot 2 was placed in the royal fern zone of the Floodplain Scour Community

Eight transects were laid out in the five riverscour sites. Ferncliff and Double Hydraulic had one transect, the other three sites had two transects. Groundcover, including vegetation and substrate was recorded by species or substrate type in one meter increments starting at the transition from the riverscour to the upland and ending in the river. The accumulated inches of cover translates to the percent cover of the species within the 1m segments along the transect. The pattern in substrate and vegetative cover generally reflected the values observed in the plots; however, there were differences, such as percent cover of bedrock, due to placement of plots within different zones of the riverscour. General patterns are apparent in the data, and are confirmed by simple observation. Overstory cover is greater at the beginning of the transects near the transition to the upland, where frequency and severity of flooding events is lower. Towards the end of the transects, vegetation is limited to royal fern. Most transects ended in bedrock or boulder cover.

These data are available to be map elevation and inundation data for each site. The transects ranged from 10m at Drake Run, a very narrow scour, to just under 50m at Ferncliff. Substrate ranged from deposits of sand and gravel to large unvegetated expanses of bedrock and boulder. When documented on the transects, Marshallia and its micro-habitat associates were found toward the river side of the transect, on all transects except at Dimple Run. In general, we found that the broader the riverscour, and thus the longer the transect, the greater the diversity in vascular plant species was recorded along the transect. Wide riverscours often have a greater diversity of microtopography, and plant species.

Table 4. Ecological characteristics documented in Natural Heritage Plots established at five sites in riverscour ecosystems on the Youghiogheny River.

Site	Trans-ect	Total Length (m)	% Cover								Vascular Species Richness
			Bedrock/ Boulder	Cobble	Sand/ bare ground	Litter	Bryophyte	Tree	Shrub	Herb	
Dimple Rock	1	12	79.9	0	<1	1.3	14.1	25.0	41.3	4.5	9
	2	11	75.9	0	2.7	0.9	20.0	39.1	27.5	20.1	22
Double Hydraulic	1	33	76.2	0	5.6	4.8	3.9	35.0	24.1	26.1	41
Drake Run	1	10	0	69.1	11.0	9.0	13.3	24.0	26.9	43.2	25
	2	16	1.25	31.5	17.8	24.3	11.25	27.5	44.0	57.4	29
Ferncliff	1	49	18.0	32.1	0.2	10.1	1.0	10.4	35.0	38.5	58
Meadow Run	1	19	85.3	0	0.8	6.2	3.6	19.4	8.2	4.4	16
	2	20	91.0	0	4.0		1.5	19.7	4.5	7.7	12

The royal fern zone is clearly different in species composition from the rest of the riverscour, forming a distinct zone of consistent cover on the rocky shore of the Youghiogheny. However, NatureServe and the West Virginia Natural Heritage Program do not recognize this as a distinct community, and include it as part of the "Appalachian Acidic Sandstone Rivershore Prairie" – CEGL006623. This association is described as having a "mixed shrub and herbaceous physiognomy, with herbs dominating the general aspect; in places, it may include a few taller trees less than 30% in cover (Vanderhorst et al. 2010; NatureServe 2020). Like the bare bedrock and boulder cover, the royal fern-dominated zone reflects the variation and complexity of the scour community.

These zones appear to differ in geographic position on the river floodplain scour, distance from flowing water, elevation above the river, and in hydrology. These should be further investigated. It is presumed that differences in hydrodynamics across the site results in different extents of these two zones within the flood riverscour area.

Riverscour Ecosystem Hydrology

Field camera Monitoring

We visited each site approximately once each month between April 1 and December 31, 2020 to down load images, change batteries, and readjust camera angles. Due to drought conditions on the Youghiogheny throughout the study period, we did not get as high flows as we expected (Figure 20).

a)

2020-12-14, 1:30pm
Gage height = 2.34ft; flow = 230cfs

No major high water events have occurred on this site since the end of the growing season as evidence by the standing vegetation.

b)

2020-12-22, 5:00pm
Gage height = 3.02ft; flow = 1770cfs

c)

2020-12-25, 1:30pm
Gage height = 8.62ft; flow = 9970cfs

A large rain event over the preceding two days significantly increased the flow in the river. The staff gage is completely submerged, indicating that at least two feet of water is covering the riverscour prairie.

d)

2020-12-28, 8:30am
Gage height = 3.75ft; flow = 2430cfs

The river levels have decreased; however, the water reaches the base of the tree that the staff gage is mounted on.

Figure 20. Example time series from December 2020 of field camera image from the Ferncliff Peninsula - End site.

The entire scour, including the *Marshallia* zone, the shrub zone, and royal fern zone, as well as exposed bedrock and boulders remained above the flowing water throughout much of the study period, except for three occasions (2020-10-30, 2020-11-12 , and 2020-12-25) where water covered portions of the bedrock, royal fern, and *Marshallia* zones. The flow of 12,100 cfs, recorded on 2020-12-25 resulted in inundation of the *Marshallia* zone at

Ferncliff Peninsula - End, Meadow Run Ledges, Double Hydraulic, Dimple Rock, and assumedly Drake Run (no cameras were present). Based on flood debris and sediment, much of the shrub zones were also flooded at this time.

We developed "hydrograph videos" for each riverscour site where camera have been deployed and provided them to TNC and the USACE. These "videos" represent a period of still images recorded in 15 minute time intervals and when viewed in rapid succession, appear as continuous video or movie. When gauge data is overlaid on top of these videos, one can visualize the value of the river level and impact of the water on the riverscour.

Select hydrograph videos from the high flow event on 2020-12-25 are attached to this report. They are:

- Dimple Rock – Camera 1 – December 2020: https://vimeo.com/502333082
- Dimple Rock – Camera 2 – December 2020: https://vimeo.com/502342542
- Double Hydraulic – Camera 1 – December 2020: https://vimeo.com/502327091
- Double Hydraulic – Camera 2 – December 2020: https://vimeo.com/502330822
- Ferncliff - Camera 1 - December 2020: https://vimeo.com/502443022
- Ferncliff - Camera 2 - December 2020: https://vimeo.com/502447536

As expected, battery usage was an issue with the cameras, especially when set for 24 hour recording using the flash. We had no issues with tampering of the equipment, mostly notably a tree that one of the cameras were mounted on broke and fell over in a storm. We did not adequately account for vegetation growth when placing the camera at a few sites, as tall grasses obstructed some of the cameras view. The cameras used in this study have a relatively narrow field of view (approximately 38°), we recommend attempting find a camera with as wide a field of view as possible.

Despite some issues with the camera equipment, we strongly believe these cameras to be viable tools for monitoring river flow. Videos produced from these cameras provide an excellent communication tool to show how rising water levels affect riverscour ecosystems.

Hydrological Modeling

A preliminary analysis of riverscour inundation patterns and frequency, related to *Marshallia* and other rare plant habitat based on data previously collected of the five sites suggested that these areas were predicted to flood more frequently than what was observed in the field cameras. However, 2020 was an exceedingly dry year and the number of high water events was much lower than in previous years (Figure 7).

Our first attempt at calculating inundation frequency of the riverscour habitats using PAMap LiDAR appeared to be an overprediction of scour frequency. This was likely due to the aforementioned lidar breakline issue where the breaklines crossed over the riverscour habitat, effectively placing the riverscour at the same elevation as the river channel, and thus they showed scour inundation. Our UAV derived mapping and newly created breaklines did not suffer from this issue and generally produced a more reasonable or expected representation of inundation frequency. Inaccuracies in the LiDAR data resulted higher numbers still and inundation frequency generally improved from an earlier run based on LiDAR only data (unpresented data).

The HEC-RAS model indicated inundation of all five focal riverscours at discharges gaged at Ohiopyle ranging between 7,677 and 23,775 cfs (Figure 21). During the study period beginning when the cameras were deployed and ending on 2020-12-31, only one event occurred with a flow exceeding 7,677 cfs. This is consistent with observations from the field cameras indicating very little flooding during the summer of 2020.

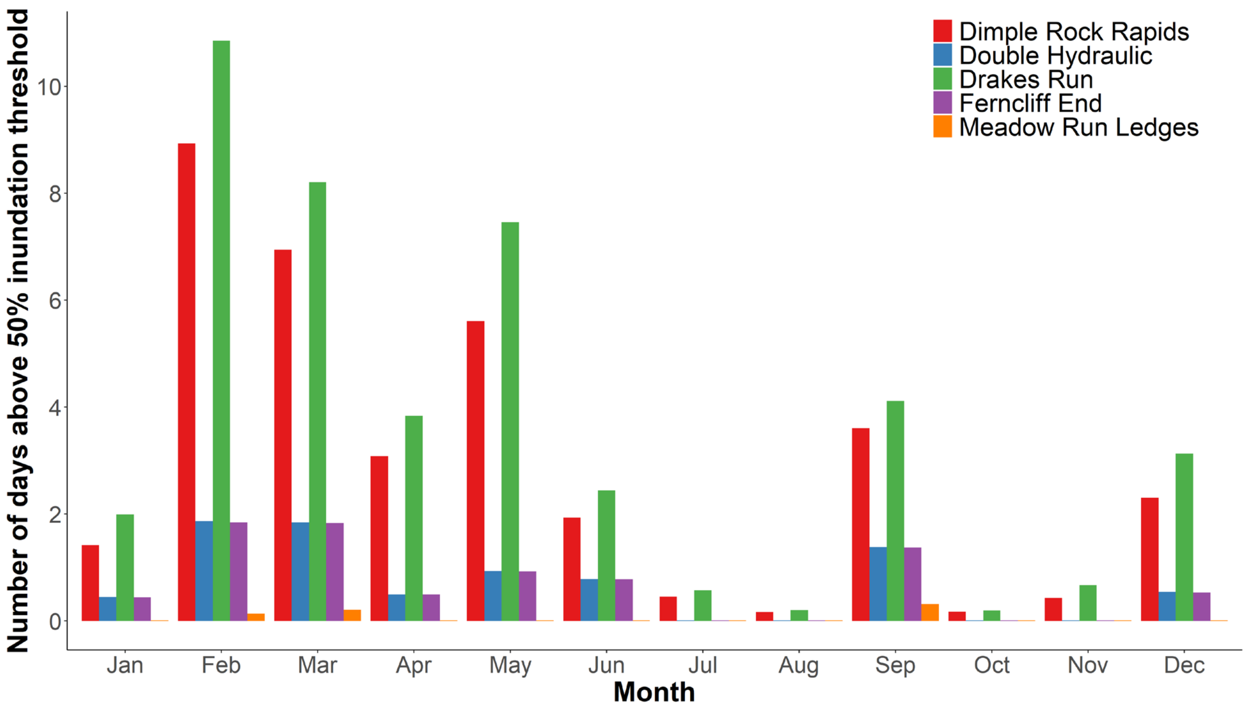
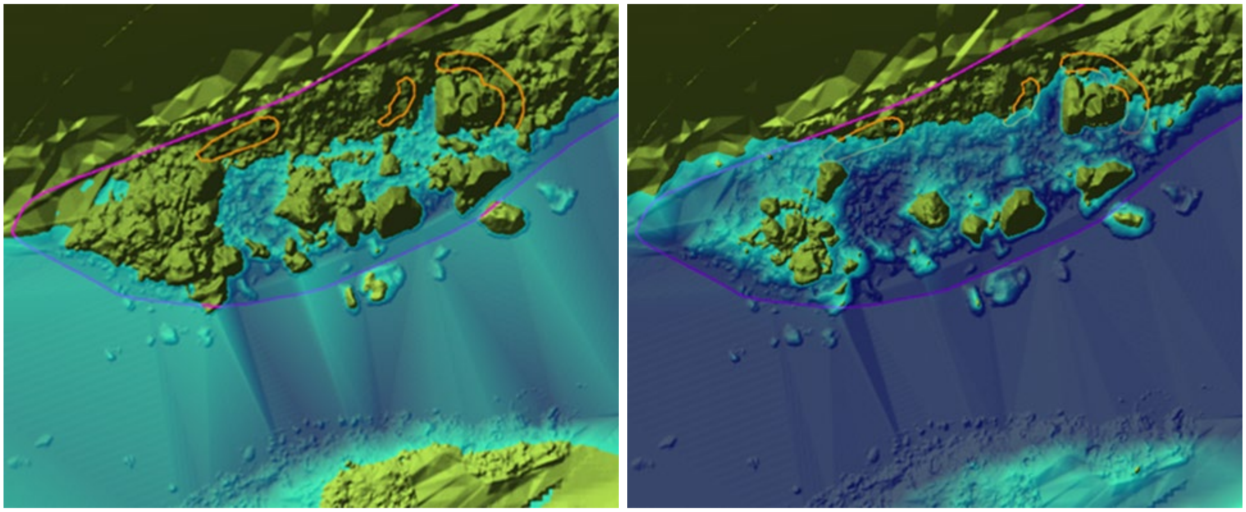


Figure 21. Percent of days 50% of the documented Marshallia populations are 50% inundated at five riverscour sites along the Youghiogheny River. Flow rates, as documented at the Ohiopyle gage that inundated approximately 50% of the Marshallia habitat are: Drakes Run = 7,667cfs; Dimple Rock Rapids = 8,181cfs; Double Hydraulic = 11,842cfs; Ferncliff End = 11,881cfs; Meadow Run Ledges = 23,775cfs.

Models and field cameras indicate that the duration of flooding events is rather short. In particular, within the areas that support *Marshallia*. Field cameras only recorded 2 events where the *Marshallia* was inundated at any of the sites between April and December 2020; hydrological models showed that only the highest flows were sufficient to inundate the *Marshallia*. In the models, Ferncliff End and Double Hydraulic were very similar in terms of inundation frequency with riverscours exhibiting less than 5 days of 50% inundation (Figure 21). Dimple Rock and Drake Run experienced the most days with flows high enough to flood over 50% of the riverscour. Meadow Run Ledges is the one outlier where it seems to rarely be inundated. However, this site is primarily a bedrock ledge perched above the water, and may be out of range of all but the highest flows. USACE hydrologists estimate that it takes a roughly 5-year storm to inundate the Meadow Run Ledges, whereas the other sites are probably inundated at least once a year (John Sourbeer, personal communication). Inundation mapping for two flows from the hydrological modeling for the Double Hydraulic site is presented in Figure 22. A median spring (Mar-Apr) flow is presented in Figure 22a, whereas a high flow that would likely inundate the *Marshallia* habitat is presented in Figure 22b. While we have not completed a formal analysis of the flows recorded by the field cameras, a preliminary review of the images captured during the 2020-12-25 event showed that the area of inundation recorded by the cameras at 2,500 cfs and 11,000 cfs roughly matches the area predicted by HEC-RAS model. More review of this data is needed including calibrating the model at a variety of flows and across more of the focal sites.



a) 2,500cfs (~spring median flow) b) 11,842cfs (~50% inundation)

Figure 22. Output from inundation modeling HEC-RAS for the Double Hydraulic site under two flow conditions: a) 2,500cfs which approximates a typical spring flow; and b) 11,842cfs which has inundated approximately 50% of the Marshallia habitat as indicated by the orange polygons.

Conclusions and Next Steps


Figure 23. The riverscour at Double Hydraulic (photo by PNHP).

Ultimately, the identification of riverscour habitats and management needs of the plants within these riverscour habitats is necessary for implementing new flow prescriptions for the river downstream of the Youghiogheny Dam. Through this and other studies we have collected evidence that *Marshallia* appears to occupy a specific area on the scour, where substrate and floodplain processes such as scour, inundation, ice, and erosion/deposition create suitable conditions for establishment and persistence. Areas that are too wet or inundated are typically dominated by royal fern, whereas areas that are too dry succeeds to shrubs and this area is where invasive plants (e.g. knotweed) may be really problematic (Figure 23).

Other major threats to riverside riverscour communities include changes to river hydrology (especially dams), habitat conversion by development, water pollution, trampling in areas popular for recreation, and the establishment and spread of invasive plant species. Often, these threats occur together.

Climate change may also greatly influence the composition of the plant communities of a riverscour. Without the freeze-thaw and naturally occurring ice-scour, trees like silver maple and sycamore previously unable to grow to full size may flourish and form an overstory. This could result in the riverside being less habitable for some of our rare species, like *Marshallia* that require the open, prairie-like conditions found in a riverscour. Dams and large structures like bridge abutments alter the disturbance regime and ice and water scour with the bedrock and cobble zones of the high velocity rivers in the Appalachian Mountains. While we will not be able to address climate change or mitigate the impact of existing transportation infrastructure, we believe that we can improve the conditions for globally important species like *Marshallia* on the riverscour by managing the flows from reservoirs to replicate natural disturbance regimes.

While the preliminary inventories of sour sites on the Youghiogheny River revealed new insights into fine composition and structure of the plant community zones, and field cameras documented the frequency, intensity, duration and timing of flood events, more work should be done to fully understand the dynamics of this ecosystem and how regulated river systems differ from those without flood control structures, such as the Youghiogheny River Dam.

From the camera data we captured, we are able to compare the flooded area of the scour with inundation models and gauging station data to get a better idea of what certain flows mean to the presence/occurrence of *Marshallia* in the floodplain scour community. The 2020 growing season was extremely dry, with river flows from May to September ranging from 488 to 3,030 cfs (high flow May 15, 2020). After mid-May, gauging station data indicates that flows rarely eclipsed 2,000 cfs. This means that the river scour, and particularly the *Marshallia* zones on the river scour remained dry from the time from flowering to the end of the growing season. We may conclude that the *Marshallia* zone is therefore not “flooded out” during the dry years, such was the case in 2020. However, historic hydrological data and inundation models indicate that these sites experienced flows at greater than 2,500 cfs at least 2 times over the past 10 years. It is unclear how specific high water events impact the *Marshallia* zone, but as the lower elevation zones on the floodplain tend to support royal fern, sycamore “shrubs” and emergent wetland plants such as water-willow, an increased frequency and duration of inundation may result in a shift towards these species and away from *Marshallia* and its associates. With climate change expected to result in a greater amount of precipitation in the region, and dam releases regulated to maintain water levels for recreational boating, it is likely that we may observe this shift.

Following this past field inventory, we recommend the following areas of study to provide the baseline information needed to assess the ecosystem change following restoration of natural flows in the Youghiogheny River:

1. Determine long term trends in the inundation of the Youghiogheny River using flow data from the Connellsville and Confluence USGS gauging station data.
2. Count inundation events and estimate duration for each inundation event (also long term trends).
3. Obtain annual temperature data for each site to investigate relationship between erosion and sedimentation in relation to number of days above freezing and to better understand the role of river ice in protection and maintenance of scour communities.
4. Improve terrain data at riverscour sites to revise/improve "inundation flows" and obtain more precise elevations across all riverscour sites. Make riverscour sites 2D flow areas to improve velocity/shear stress estimates.
5. Map the vegetation of riverscour zones in relation to elevation and substrate depth. Preliminary investigations revealed Marshallia and its associates occur on shallow sandy, to sandy loam soils too shallow for tree and shrub establishment and deep enough for dry rapidly following flooding. Understanding the micro-habitats (substrate depth and elevation) will lead to a better understanding of available habitat of Marshallia.
6. Develop a conceptual ecological model (CEM) for the floodplain scour community of the Youghiogheny River and other Appalachian rivers.
7. We recommend establishing a formal vegetation monitoring program at sites along the Youghiogheny to capture changes in vegetation as they relate to frequency, duration, timing, and severity of flood events on riverscour sites. In addition to field cameras, sediment deposition studies should be undertaken and other techniques to monitor the duration of flood events should be investigated (see Van Appledorn et al. 2019).
8. Compare vegetation and substrate variables of the Youghiogheny River riverscour with those of a nearby unregulated river, such as the upper Cheat River in West Virginia, including obtaining drone imagery. It is impossible to determine the impact of the flow management of the Youghiogheny River Dam on the riverscour ecosystem and *Marshallia* population without comparing the riverscours of the flow-regulated Youghiogheny River with riverscour areas of unregulated rivers in the Appalachian Mountains. Further, we recommend development of hydrological models for each site and compare them to the Youghiogheny sites to determine the difference in severity, duration, and timing of flood events during the growing season. Comparison of the sites along the two different rivers (flow-regulated and non-regulated) should contribute to a strategy to modify discharge rates to improve flow conditions for the Marshallia and other plant species of the riverscour on the Youghiogheny River.

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Appendix A – Elevation Processing Methods

The goal of this workflow is to merge the more detailed elevation data derived from UAV (unmanned autonomous vehicle/drone) mission sites with the less detailed elevation from the PAMAP Program. The resulting elevation dataset will use the elevations derived from the UAV sites but retain the elevations of the PAMAP Program so as to preserve a completely continuous elevation raster dataset. The resulting merged elevations are technically intended for different geographic scales but allow for local variations to be present for the purpose of modeling riverscour areas with hydraulic analysis with more precision.

PAMAP Lidar Processing

The Pennsylvania Department of Conservation and Natural Resources (DCNR) PAMAP Program collected LiDAR data and orthoimagery from 2003 to 2008 covering the entire Commonwealth (PAMAP 2020). Data was collected in April of 2006 in Fayette County, PA, where Ohiopyle State Park is located (PAMAP 2006[1]). According to the LAS file properties accessed using ArcGIS Pro, the LAS files conform to the LAS specification 1.1 and according to the metadata, the points are classified as described in Table 1 (PAMAP 2006[1]).

LAS Point Class	**Description**
Class 1 (Default)	These are the points that are a mixture of the remaining points after the ground classification. These would contain bridges, overpasses, buildings, cars, parts of vegetation, etc.
Class 2 (Ground)	These are points on the bare earth surface. They are from the automated processing, as well as the manual surface review.
Class 8 (Model Key)	These are the educated, thinned points to represent the final bare earth surface. This is from our automated processing. These are the points that we have used to generate the final contours.
Class 9 (Water)	These are points inside of hydrographic features, as collected by photogrammetric methods. These are from automated processing, as well as the manual surface review.
Class 12 (Non-Ground)	These are points that are identified as first of many return or intermediate of many returns from the LIDAR pulse. These are points that are most likely vegetation returns or points identified to be not on the ground surface.
Class 15 (Road Edges)	These are the points that fall within +/- 1.5' of road break lines.

Table 3. PAMAP LiDAR LAS file classifications as reported in the metadata (PAMAP 2006[1]).

Due to this limited and antiquated LAS classification scheme, the PAMAP LiDAR data was enhanced to reclassify the points to conform to the current LAS Specification 1.4 classification scheme (ASPRS 2019) to create more accurate elevation products. The reclassification workflow modifies the classification codes while maintaining the integrity of the original classifications as much as possible where classification schemes overlap (e.g., Class 2 (Ground) was maintained as ground). The reclassification workflow also identifies and removes noise points, delineates vegetation into different heights, and classifies roads and bridges using polygons created from the accompanying breakline shapefiles.

Once the PAMAP LiDAR data point classifications are enhanced, a digital terrain model (DTM) is created at 0.8-foot resolution. The DTMs created by the PAMAP Program are at four times the resolution at 3.2 feet (PAMAP 2006[2]). By decreasing the resolution to 0.8 feet, this will provide for greater detail and precision in the DTM, which is a more suitable resolution when merged with the derived UAV DTMs later in the process.

UAV Imagery Processing

A DJI Phantom 4 Pro v. 1 unmanned aerial vehicle (UAV) was used to collect ortho images (citation for the drone?). Map Pilot for DJI software, developed for iOS by Map Made Easy and used on Apple iPad, was used to plan and fly automated flight missions at each site (cite Map Pilot for DJI software?). Each flight was flown at 200 ft above ground level using terrain awareness (i.e. the flight path adjusted to changes in ground elevation) and at 75 percent image overlap by an FAA Part 107 Certified Remote Pilot in June 2020.

The UAV images are initially processed using Pix4Dmapper photogrammetry software (cite Pix4Dmapper?) without using ground control points (GCPs) to produce a high-resolution orthoimagery (1.74 cm mean resolution across all sites). Using this UAV orthoimagery with the PAMAP Program aerial orthoimagery (1-foot resolution) (PAMAP 2006[3]), 3D GCPs were found for features that clearly exist on both images, such as rock points and corners of man-made structures. The PAMAP 3.2 ft DEM is used for vertical values (Z values). All GCP XY values were converted to WGS 1984 and Z values were retained as NAVD 1988 but converted to meters.

Since the PAMAP Program collected orthoimagery in conjunction with the LiDAR data collection (PAMAP 2006[1]), the LiDAR data is aligned with the orthoimagery. This allows the UAV photogrammetry-derived orthoimagery and point cloud data to be more accurately aligned with the existing PAMAP Program data for when the data is when merged with the derived UAV DTMs later in the process.

The GCPs are imported into the project and matched to the UAV images in Pix4Dmapper. In the Pix4Dmapper GCP/MTP Manager, the GCP horizontal and vertical coordinate system were set to WGS 1984 and Arbitrary, respectively. This results in the output point cloud vertical values to align with PAMAP 3.2 ft DEM vertical coordinate system, NAVD 1988. The UAV images are processed again using Pix4Dmapper using the matched GCPs with the output horizontal and vertical coordinate systems set as WGS 84 / UTM zone 17N and Arbitrary, respectively. The resulting mean RMS error across all sites after processing with the GCPs is 0.166 m (0.545 ft).

Classify UAV Imagery Water, Bare Rock, and Vegetation Areas

We used the image classification toolset in ArcGIS Pro to classify each UAV image into areas of rock, water, and vegetation. This was converted to a polygon layer for use in generated.

Process UAV LAS Point Files

The output photogrammetry-derived point cloud (LAS file) was processed to determine the ground points that will be used to create the final DTM. The process is complicated by the number of points in the output photogrammetry-derived point cloud from Pix4D. Therefore, this process starts by thinning the point cloud to a target resolution of 0.4 feet, or one-half the final output resolution of 0.8 feet. Then the points are analyzed for noise and noise points are removed. This thinning and noise analysis reduces the number of points by 64% to 82% allowing for both easier and faster analysis.

After thinning and noise analysis, the points are classified as water, bare rock, and vegetation by height using ArcGIS Pro LAS tools and the UAV imagery classification areas. The points classified as ground and water are then extracted. The resulting ground and water points are analyzed further using automated tools to remove more extraneous, non-ground points, however there are still points that are incorrectly classified. Therefore, the last step of this process requires a systematic review of the point cloud data to manually classify ground points that are misclassified in ArcGIS Pro using a 3D Scene.

At this stage, a systematic error was discovered between the UAV photogrammetry-derived point cloud elevations and the PAMAP LiDAR point cloud elevations that resembled a sloped plane where elevations were slightly higher at one end of the site area and slightly lower at the other end in the downstream direction of the Youghiogheny River. This systematic error was present at each site, but it is unclear what the origin of the error was, though likely something in the photogrammetry process. Therefore, a methodology was developed to align and correct the elevation values of the UAV photogrammetry-derived points to the PAMAP elevations during the conversion from the point cloud to a DTM raster dataset.

Create DTM Raster

The elevation alignment and correction process requires first creating an initial UAV 0.8 ft resolution DTM raster using the extracted and classified ground UAV photogrammetry-derived points, where non-ground areas are represented as NoData values in the raster dataset. Using the ArcGIS Pro Raster Domain tool, a line feature class is created on the edge pixels of the DTM that represent the edge between water and ground areas. The line vertices are converted to points with the elevation stored as the Z value. The points are then interpolated to a raster dataset using the Natural Neighbor method. This essentially creates a raster representing the approximate water elevation where the ground and rocks above the water level are sliced off the elevation raster. This can be used to isolate the more detailed elevation features, especially the rocks within the river, so that the correction is averaged for the geographic plane beneath the whole feature.

The final elevation correction is calculated using raster math by first subtracting the interpolated Natural Neighbor raster from the PAMAP 0.8 ft DTM to create a difference raster. The difference raster is then added to the UAV 0.8 ft DTM. And lastly, the maximum value between the UAV 0.8 ft DTM and the PAMAP 0.8 ft DTM is used as the final elevation values in the DTM.

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Appendix B – Quantitative Community Plot Sampling Data Form

PNHP Quantitative Community Characterization Draft: Summer 2019

ObsArea: ______________________ ObsAreaCode: ________ Project ObsCode: ________________

Assessment Area

Observation Type: ____________________ EcoObs Code ______________

Site Name: __________________ Ownership: ____________________________ Confidentiality ________________________
Location: ___________________________ County: _____________ Twp: ______________ Watershed: ____________________
EO Information: Elcode: __________ State EO Rank/Date: ____________ State EO size (acres): ____________________________
Survey date: __________________ Surveyors: ____
UTM/Lat_Long: _ _ _ _ _ _ _ , _ _ _ _ _ _ _ _ PDOP: _____ Map datum: __________ UTM Zone: ________ GPS Unit: ______

Directions to Site:

Assessment Area/Site Description:

Representativeness Comments:

Community/Stand Classification : PA Community Type: ____
NVC Type: CEGL Code: ______________________ Classification Comments: ____

Environment

Representative sketch of stand and landscape position and location of plot (note location of GPS point and direction of plot boundaries)

Picture No. ______________ Photographer: ___________

Environmental Comments:

Topo Position:
- ___ Interfluve (ridgetop)
- ___ Low slope
- ___ High slope
- ___ Toe slope
- ___ High level
- ___ Low level (terrace)
- ___ Midslope
- ___ Channel wall
- ___ Backslope
- ___ Channel bed
- ___ Step in slope
- ___ Basin floor/depression
- ___ Alluvial
- Other: __________________

Landform: ___________________________

HGM Class & subclass (Brooks):

1) **Flat** - mineral, organic,
2) **Slope** – topographic, stratigraphic,
3) **Depression** – temporary, seasonal, perennial, human impounded excavated beaver impounded,
4) **Lacustrine Fringe** – permanently, semi-permanently, intermittently or artificially flooded,
5) **Riverine** – intermittent, headwater complex, upper perennial, lower perennial, floodplain complex, beaver-impounded, human-impounded,
6) **Estuarine Tidal Fringe** - estuarine lunar intertidal, wind intertidal, subtidal, impounded

Hydrology(Cowardin):

Upland: **Dry Dry-Mesic Mesic**

Wetland:

1) **Palustrine** – Forested, Scrub-shrub, Emergent,
2) **Lacustrine** – Aquatic Bed, Floating ,
3) **Riverine** – Tidal, Lower, Upper, Intermittent, Ephemeral

Hydrologic Regime:
- ____ Permanently flooded
- ___ Semipermanently flooded
- ____ Seasonally flooded
- ____ Seasonally saturated
- ____ Intermittently flooded
- ____ Temporarily flooded
- ____ Artificially flooded
- ____ Saturated
- ____ Never flooded/inundated

Unvegetated Surface: ______Total
- ___ % Surface water
- ___ % Litter, duff, wood <10 cm dbh
- ___ % Wood > 10 cm
- ___ % Rock
- ___ % Sand
- ___ % Bare surface
- ___ % Other: _______

Water Source (wetlands):
- ___ Precipitation
- ___ Surface/overland flow
- ___ Groundwater
- ___ Water body inundation
- ___ Overbank flow

Average soil texture:
- ___ sand
- ___ clay loam
- ___ sandy loam
- ___ clay
- ___ loam
- ___ peat
- ___ silt loam
- ___ muck
- ___ other

Depth of sample _____ cm
Soil sample # ______________

Physiography:

Slope %: ________ Aspect: _________ Beers Aspect: _____
Elevation (m): _____ Geology: _______
Hummock height (peatlands) (cm):: ______
Distance to River center: (floodplains) (m): ______
Depth to Ground Water (cm): ________

Soil drainage:
- ___ Very rapidly drained
- ___ Rapidly drained
- ___ Well drained
- ___ Mod. well drained
- ___ Somewhat poorly drained
- ___ Poorly Drained
- ___ Very poorly drained

Soil Detail: Soil profile description: note depth, texture, and color of each horizon. Note significant changes such as depth to mottling, depth to water table, root penetration depth, **circle depth of soil sample**

Pit#/Horizon	Depth	Color	Texture	pH	VonPost	Comments

PNHP Quantitative Community Characterization Draft: Summer 2019

Vegetation

Plot/ObsArea Code: ______________________ Plot dimensions: ______________________

Leaf Type	Leaf Phenology	Physiognomic Class			Cover Class	Height Class
___ Broad-leaf	___ Deciduous	___ Forest	___ Woodland	T2 Tree Canopy		
___ Mixed broad-leaf/needle-leaf	___ Mixed deciduous/evergreen		___ Shrubland	T3 Tree Subcanopy		
___ Needle-leaf	___ Evergreen	___ Dwarf Shrubland		S1 Tall shrub		
___ Broad-leaf herbaceous	___ Perennial	___ Non-Vascular	___ Herbaceous	S2 Short shrub		
___ Graminoid	___ Annual		___ Sparsely Vegetated	H Herbaceous		
___ Pteridophyte				N Non-vascular		
Cover: 1 <1% 2 = 1-5% 3a = 5-10% 3b = 10-25% 4 = 25-50% 5 = 51-75% 6 = 76+ % OR: Real Cover Y/N **Height: (1) <.5m (2) .5-1m (3) 1-2m (4) 2-5m (5) 5-10m (6) 10-15m (7) 15-20m (8) 20-35m (35-50m (10) >50 m**				Overall canopy cover		

Species / percent cover: starting with uppermost stratum, list all species and % cover for each in the stratum and total % cover. For forest and woodlands, record the DBH of all trees above 10 cm diameter.

Species	T1	T2	T3	S1	S2	H	NV	C	Spec. or DBH (for trees >10cm in column 1)	T1	T2	T3	S1	S2	H	NV	C
									Water Quality (wetlands): temp: __________ pH: ___________ EC: __________ TDS: _________								

Appendix C – PNHP Documenting Plant Element Occurrences for the Pennsylvania Natural Heritage Program

Developed November 2004

This document is organized to follow the fields in the PNHP Field Form Database, but the guidelines really refer to field techniques. It is hoped that this document will prove useful enough for biologists to consider carrying a copy in the field.

- **Size of EO**
  - It is first important to understand the concepts of genet and ramet, for which it can be difficult to find definitions. From Scrosati (2002) "Clonal plants are those that spread vegetatively by producing a number of similar functional units (such as shoots) that are potentially able to live on their own if they become physically separated from the parent plant. Such vegetative units are termed ramets, whereas the entire plant is termed genet."
    - *Genet: A unit or group derived by asexual reproduction from a single original zygote, such as a seedling or a clone.* (Lincoln et. al., 1998). Thus, a genet can consist of a single stem or a clone of many stems that are essentially genetically identical.
    - *Ramet: A member or modular unit of a clone, that may follow an independent existence if separated from the parent organism* (Lincoln et. al., 1998). This is a useful concept for evaluating the size of occurrences for two reasons:
      - Determining the number of genets in the field for an asexually reproducing species is often not possible.
      - The number of stems or clumps (ramets) is often a better indicator of the viability of an occurrence than is the number of genets.
  - It is inadvisable to estimate the number of plants without counting a portion first. There is a tendency to significantly underestimate occurrence size.
  - Count a reasonable number of plants (25 or 50 typically) and get a good feel for what that many plants looks like. If this number is very small relative to the whole occurrence, visually extrapolate to estimate what 100, or even 1000 plants looks like. While mentally adjusting for differences in density, use this basic unit as a template, and walk around the occurrence adding up the number of units to obtain an estimate.
  - How to count clonal species
    - *A large portion of our native plant species are clonal by rhizomes. If possible, estimate both the number of genets and the number of ramets.*
      - Estimating number of genets. Plants that produce multiple or branched rhizomes tend to form more or less circular clones. As these clones age, they may merge, making it difficult to determine how many genetically unique plants are present. Sometimes careful observations can provide some insight though. Step back to observe the occurrence if possible; high ground is good.

- Look for somewhat circular patterns in the distribution of stems.
- Look for slight differences in color (especially in the fall) or phenology; individual plants show unique characteristics as one would expect from animals, although typically the differences are much more subtle.
- Document how you obtained your estimate. An estimate based partly on speculation can be useful if (and only if) the nature of the speculation is known.

▪ Estimating number of ramets.
  - A plant ramet is usually either a stem or a clump. Clumps can also be genets though, and field workers do not always have the resources at hand to make this determination. For example, Carex pensylvanica and C. communis both produce clumps, but a clump of the later species is likely to represent an entire genet, while in the former species a clump is likely to be part of a larger clone, the clumps being linked by rhizomes.
  - Count clumps if it is reasonably clear what constitutes a clump. This is the most useful way to keep track of the size of an occurrence whether or not the clumps are connected by rhizomes.
  - If you are counting clumps, it can be useful to estimate the average number of stems in a clump. This is especially important for loosely tufted species, when what constitutes a clump can be subjective.

▪ More important than distinguishing between ramets and genets is estimating occurrence size in a repeatable way and clearly documenting your method. Make sure it is clear what you counted as a ramet or a genet. In this way, someone can later deduce whether the occurrence is declining, stable, or increasing by reproducing your method.

- **Phenology**
  - It is often adequate to simply check the category that applies. If the population exhibits more that one phenological state, check all that apply, or include percentages. Consider estimating or counting percentages if you feel it is relevant to assessing the age or health of the population. This data may be used to help time future surveys, so include information that may be relevant such as if and why the plant may have flowered earlier or later than normal.
  - For bryophytes and pteridophytes, use the blank category to indicate appropriate phenologies. Typically this consists of leaf vs. states of sporangia, but it can also include gametophyte phenologies, which are important and easily overlooked. Always look for gametophytes when assessing an occurrence of a pteridophyte.
  - Note if vegetative propagules, such as gemmae, turions, bulbils, or adventive deciduous shoots are present.
- **Vigor**
  - This can be difficult to assess without extensive experience with the species and/or the specific occurrence. If you don't have the experience to provide the context to check a box in a meaningful way, just leave it blank.
  - Comments are usually more useful than checking a category. "No new growth observed" with no box checked is much better than checking "feeble", especially

if you are not sure how much new growth would be expected for the species at the time you are documenting the occurrence.

- **Age structure**
  - Ignore for annual species (addressed in phenology).
  - Mature refers to reproductive maturity.
  - It is often not worth the effort to come up with precise values for age structure. Record what you think is relevant to assessing how well the population is regenerating.
  - If you are documenting a perennial species and can find few or no juveniles, this is important to note; and you should then consider whether there might be any disruptions in the life cycle such as:
    - *Absence of obligate pollinators*
    - *Absence of male or female plants (for dioecious species).*
    - *Lack of multiple genets (for partially or completely self-incompatible species).*
    - *Excessive herbivory on reproductive parts*.
- **Evidence of Disease, Predation, or Injury**
  - No need to populate this field every time, but you should get in the habit of thinking of these things every time you document an EO. How much effort you should put into this activity is dependent on what is known or suspected about threats from these sources (or, in some cases, dependency of some other species of conservation concern on the plant as a food source etc.).
  - Certain symbiotic relationships should be recorded here. No need to say that the oak tree has mycorrhizal fungi, but if you see a fruiting body growing from the base of the tree, note it. Look for evidence of animal pollinators (if applicable) and dispersers. Pollination biology is often a significant gap in the understanding of the ecological requirements of rare plant species.
- **Hybridization Issues**
  - If hybridization is common in the genus, express your level of confidence regarding the presence of hybrids in the area.
  - If any other species in the genus are present that might plausibly hybridize with the element, list them.
- **Habitat of EO**
  - Specific is good, but brief is often adequate. Consider the specificity of the plant's requirements as well as the rarity of the element when deciding detailed a description is appropriate.
  - Natural community can be used as the habitat, or in addition to the habitat. "Cattail marsh" might be adequate for a habitat description, but "2-5 dm-deep cattail marsh" or "pools in cattail marsh" might be better. In the latter cases, it is better to clarify that you are specifying a standardized natural community: "Cattail marsh (Fike classification), hydric areas of the marsh in water ca 2-5 dm deep".
- **Substrate**
  - Indicate the depth or depths at which you observed the soil. If your understanding of soils permits, express this in terms of soil horizons.
  - Geology and soils types can be determined from maps geology or soil survey maps as well as from direct observation, both with inherent limitations on accuracy. Specify which. Of course, it is best to have both, but this is not always necessary.
- **Associated Species**

- Only include plants that are growing near the element and in the same habitat. A good rule of thumb is herbaceous plants within 1 meter, and woody plants within 5 meters, excluding other habitats. However, unless you are involved in a quantitative study (in which case you should probably be recording data in a different format), this usefulness of this data will be related only to the extent to which it helps to describe the habitat of the element at this location. If you are in a fen that is dominated by Carex interior, but the nearest stem of that species is just over a meter away, you should probably include it as an associate unless you have some reason to think the C. i. is excluded from the immediate vicinity of the element because of habitat differences.
- Animal species should be included if interaction with the plant element is known or suspected. Such interaction can be indirect, such as an animal that is significantly defoliating a dominant species in the habitat.

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