The Impact of Urbanization on Water Quality in Streams at Six Bunched Arrowhead Sites in Greenville, South Carolina

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Abstract

The Bunched Arrowhead, *Sagittaria fasciculata,* is an endangered plant that thrives in very limited and specific hydrologic and geographic settings in the Piedmont region of North and South Carolina. The plant requires a shallow, continuous, and slowly flowing water supply, a well-hydrated organic soil with an underlying sandy substrate, and partial or complete shade. The plant appears to be hydrologically very sensitive, yet prior to this study little was known about the hydrologic variability of its habitat and the plant's tolerance to hydrologic disturbance. The six sites reflect the broadest range of hydrologic regimes in which the plant naturally resides within the Piedmont region of South Carolina. Land cover and water chemistry data was mapped to determine the impact of urbanization on the health of Bunched Arrowhead sites. A correlation was found between land cover and the health and stability of water chemistry at each site. Two of the sites exhibited extremely stable, essentially static water chemistry data. These sites also had the most robust, healthy, and largest populations of the six sites, with plants that were taller, with broader leaves and a vibrant green color. Another two sites exhibited slight variability in water chemistry due to nearby homes and farms. These sites showed less healthy plants that were smaller and dull green in color. The other two sites have recently been impacted by residential development and exhibited very variable water chemistry. The health and populations at these two sites are now limited and have been significantly impaired with plants noticeably smaller and yellow-brown in color. The plant's distinct and sensitive habitat requirements will make it particularly vulnerable to changes in the hydrogeology and/or land cover from encroaching development. This study highlights the importance of quantifying the Bunched Arrowhead's tolerances to determine how to best manage and protect this endangered plant.

Introduction

The Bunched Arrowhead, *Sagittaria fasciculata,* is an endangered plant that thrives in very limited and specific habitat settings. The Bunched Arrowhead requires a shallow, continuous, and slowly flowing water supply typically from a groundwater seep, a well-hydrated organic soil surface layer with an underlying sandy substrate, and partial or complete shade. Roughly twenty populations of the plant are known to exist and are found in Greenville County, SC and Henderson County, NC. Concerns have been raised that increased development potentially threatens the plant's habitat at some sites through increased water runoff, reduction of groundwater recharge, and the deposition of sediments. Enhanced runoff from increased impervious surfaces can cause the hydrology of the system to be flashier, with reduced baseflow and increased hydrologic variability. The more volatile flow rates can result in erosion of habitat and deposition of sediment over leaves and roots and can alter the chemical composition and nutrient supply of a site (Newberry, 1986). Similarly a reduction in groundwater recharge can lower the water table and reduce the hydraulic gradient, thereby leading to a decrease in the amount and rate of water emanating from the seep that provides a continuous supply of water to the Bunched Arrowhead community. The plant appears to be hydrologically very sensitive, yet little is known about its tolerances to hydrologic disturbance and variability.

With increased development in some of the areas occupied by the Bunched Arrowhead, there is concern that changes in flow rates due to increased surface runoff and reduced ground water recharge will result in increased stream discharge and changes in nutrient levels with the potential to disrupt the existing Bunched Arrowhead populations (Lewis, 2007). Qualitative observation of the sites under different flow regimes suggests that healthy sites with stable water chemistry showed improved plant growth and increased plant numbers (Newberry, 1991). If this is true, then sites with increased variability in water chemistry, such as around urban areas, would inhibit plant growth resulting in smaller plant size, reduced numbers, narrower leaves, and plants that are yellowish to brown rather than vibrant green.

The intent of this study was to examine the hydrologic variability and its associated impact on the health of the Bunched Arrowhead population at six different Bunched Arrowhead sites by mapping land cover and water chemistry to determine if a correlation exits between high density urban areas and reduced water chemistry results. Water chemistry, a feature important to the plant's survival, was assessed to observe the range of chemistry and nutrients tolerated by the Bunched Arrowhead at each site. Collectively, it is important to understand the Bunched Arrowhead's habitat and hydrologic tolerances to determine how best to manage and protect this endangered plant species.

Methodology

Land Cover data was imported from ArcCatalog as a National Land Cover Database file specific to the southeast region of the United States. Water chemistry data was collected and analyzed over the summer and fall of 2013 (six total samples) for basic water chemistry analysis. Water pH, dissolved oxygen levels, and conductivity were measured on site, and water chemistry samples were analyzed for basic cations, anions, carbon and nitrogen species. The data was averaged and recorded in an excel file for each of the six sites. Sites were located in both forested and urban areas, covering a range of land use types. The latitude and longitude for each site was recorded and input into Google Earth. The six sites were saved as keyhole markup language (kml) points. The kml file was then converted into a shape file format and saved in a geodatabase. The water chemistry data was joined to the Bunched Arrowhead sites layer to generate a water chemistry table for each site. The sites were ranked from numbers1-3 based on the stability and health of water chemistry data at each site over the six sampling periods. Number one was the most stable and healthy site. This represented a site that showed large numbers of plants that were tall and vibrant green. Number 3 represented variable water chemistry data and unhealthy plants. This site showed small, brown plants and chemistry data that changes weekly. A .25 mile buffer was placed around each site based on the size of the watershed from topographic maps. The size of the watershed was calculated using topographic high points on a topography map and the watershed was then traced onto grid paper. Each square within the watershed was measured and compared to the map scale to generate the size of the watershed. Within each buffer, the amount of each type of land cover was calculated to generate a table showing land cover for each site within the watershed. Land cover was correlated to the water chemistry ranking for each site to determine the impact of urbanization on water chemistry at Bunched Arrowhead sites. Urban land was calculated as developed open space, developed low, medium, and high intensity, herbaceous, land, and hay/pasture.

Results

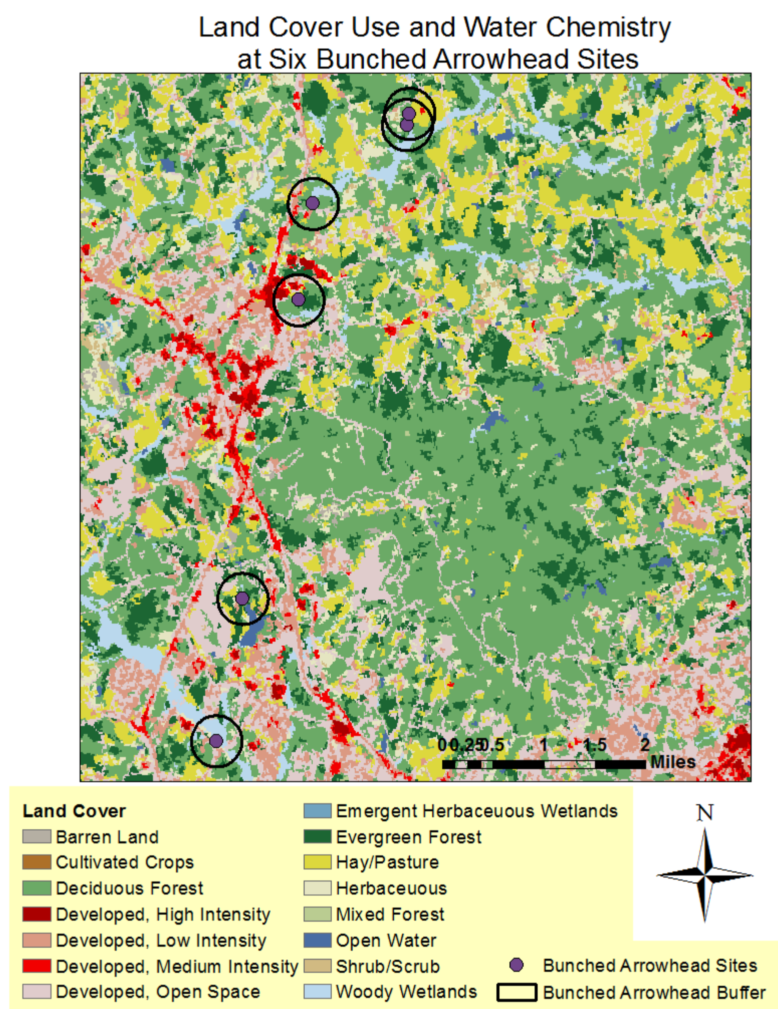

Figure 1. Map of land use for the six Bunched Arrowhead sites.

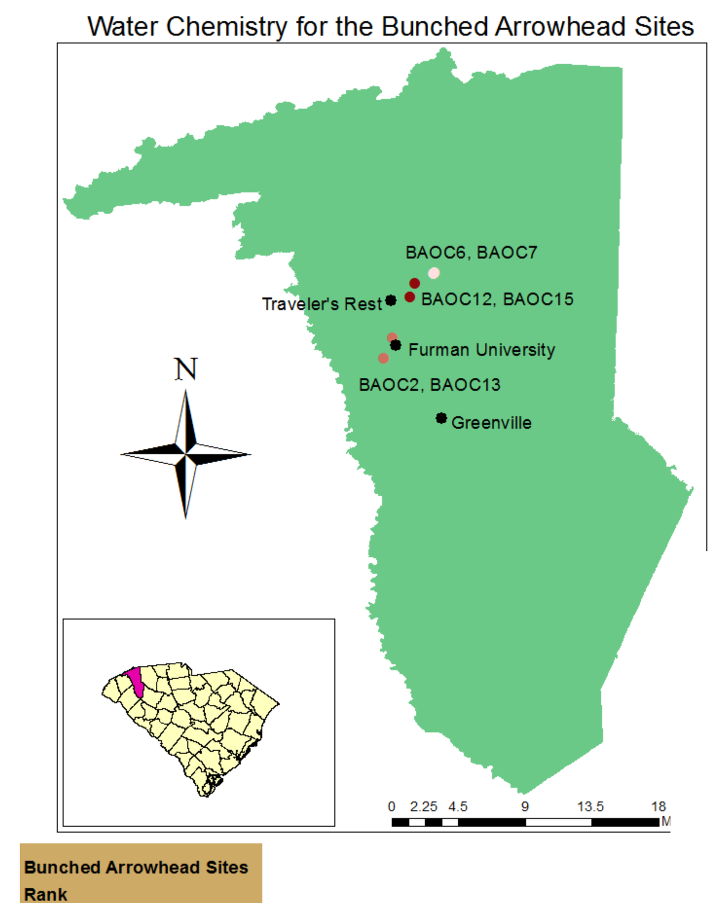

Figure 2. Map of water chemistry for each site

Figure 2. Photo of the Bunched Arrowhead plant

Table 1. Land Cover for each of the six sites

LANDCOVER	BAOC2	BAOC6	BAOC7	BAOC12	BAOC13	BAOC15
Open Water	0	0	0	0	0.00000308277	0
Developed, Open Space	0.00000702871	0.00000191132	0.00000080152	0.00000567229	0.00000832347	0.00000758361
Developed, Low Intensity	0.00000406925	0.00000049324	0	0.00000474746	0.00000203463	0.00000326773
Developed, Medium Intensity	0	0.00000061655	0	0.00000215794	0	0.00000413091
Developed, High Intensity	0	0	0	0	0	0.00000369932
Barren Land	0	0	0	0.00000067821	0	0
Deciduous Forest	0.00001356418	0.00002046958	0.00000474746	0.00002503207	0.00001029644	0.00001535218
Evergreen Forest	0.00000474746	0.00000493243	0.00000326773	0.00000129476	0.00001461232	0.00000863175
Mixed Forest	0.00000104814	0.00000043159	0.00000030828	0.00000043159	0.00000036993	0
Shrub/Scrub	0	0.00000055490	0	0	0.00000024662	0
Herbaceous	0.00000480912	0.00000487077	0.00000006166	0.00000073986	0.00000258952	0.00000073986
Hay/Pasture	0.00000006166	0.00000857009	0.00000499408	0.00000369932	0.00000776857	0.00000283615
Woody Wetlands	0.00001479728	0.00000752195	0	0.00000554898	0.00000067821	0.00000413091

Table 2. Water Chemistry for the six Bunched Arrowhead sites

Name	Na+K	Mg	Ca	SO4+Cl	HCO3	Si	DON	NH4	NO3+NO2	DOC	CO2	HCO3+CO3	Rank
BAOC2	42.7594	21.87987	35.36072	21.23108	54.46462	33.38175	65.55525	14.34378	20.10095	20.12945	80.28384	15.56084	2
BAOC6	46.2895	24.32112	29.3894	9.695383	39.0232	57.7853	49.80253	9.0739	41.12355	8.157483	86.7289	19.56847	1
BAOC7	46.00317	22.42475	31.57205	15.83757	31.14496	58.20832	73.16528	24.63048	2.204217	47.9046	57.2206	5.29388	1
BAOC12	41.16673	28.12952	30.70375	20.43202	39.90362	39.6644	26.71132	7.0884	66.20028	19.86422	63.40765	16.72815	3
BAOC13	32.49403	12.95857	54.5474	19.17893	42.3482	45.5309	50.04135	6.125417	43.83325	33.17018	47.72388	32.47186	2
BAOC15	41.85997	22.21817	35.92185	33.64175	38.73653	46.98997	57.246	22.10187	20.65215	70.26832	77.96505	11.23	3

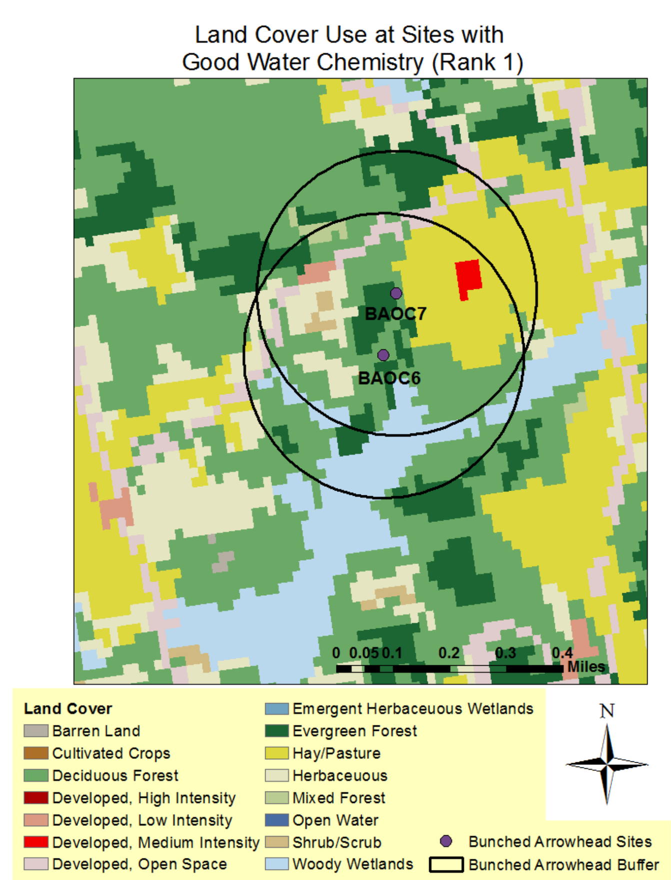

Figure 4. Land use at Bunched Arrowhead sites with a ranking of 1.

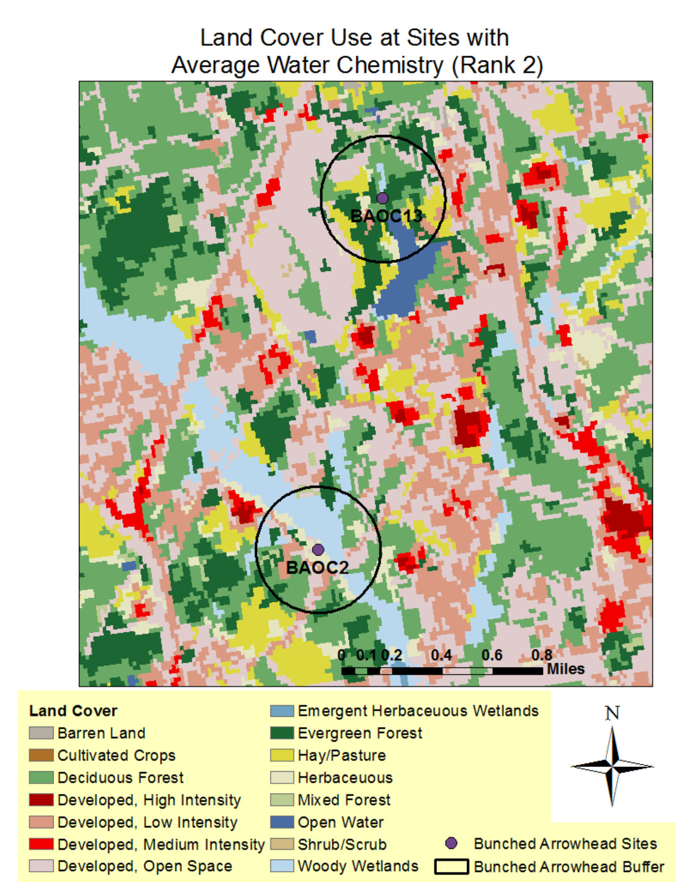

Figure 5. Land Use at sites with a ranking of 2

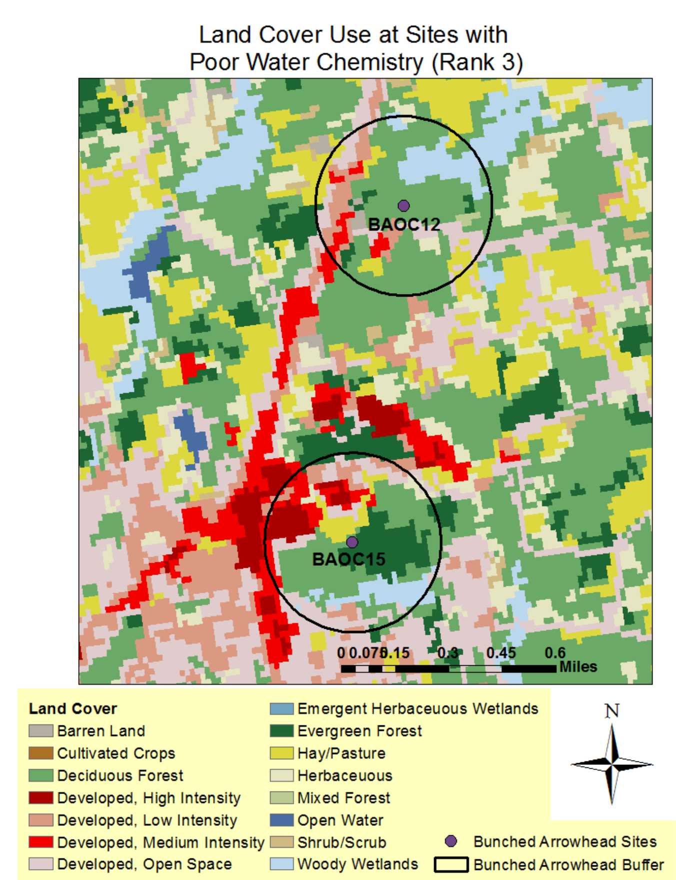

Figure 6. Land Use at sites with a ranking of 3

There is a correlation between land use and water chemistry for the Bunched Arrowhead plants. Sites with a ranking of 1 are predominantly deciduous and evergreen forests, hay/pasture, and a small amount of woody wetlands and developed open space. Sites with a ranking of 2 are predominantly deciduous forests and developed open space, developed low intensity, herbaceous, woody wetlands, and hay/pasture. Sites with a ranking of 3 are predominantly developed open space, developed low and medium intensity, deciduous and evergreen forests, and woody wetlands. Rank 3 has the highest amount of developed low and medium intensity land. Each site has a high amount of deciduous and evergreen forests because the plants grow in organic sandy soil within forests that provide shade and nutrients.

Discussion

The two sites (BAOC6 and BAOC7) that are located in drainage areas with the least amount of development show the most stable water stage while the sites (BAOC12, and BAOC15) that are adjacent to development (a school and residential neighborhood respectively) show large variability in water height after storms. Flow rates at these sites can be highly variable in response to storms of different magnitudes. Urbanization changes surrounding land and streams through removal of vegetation, compression of the soil, creation of ditches and drains, and increased roofs and roads that prevent water recharge into the ground (Booth et. al, 1997). The result is increases in the amount and speed of water as it moves downstream (Alberti et. al, 2006). Changes in the volume of water and the surrounding vegetation impacts water chemistry by increasing nutrient deposition from runoff; as water moves over the soil through urban areas it transports contaminants and minerals removed from the soil, increasing variability in water chemistry in streams.

Streams at each of the Bunched Arrowhead sites are rich in sodium bicarbonate. Cation concentrations increase with urbanization due to increased water flow over minerals in the soil that weather to produce cations. The two sites that are located in more urban areas (BAOC12, and BAOC15) show slightly increased variability.

Table 2 shows high silica concentrations due to chemical reactions that dissolve silica from minerals in the soil. Sites with greater variability in water flow (BAOC12, BAOC7, and BAOC15) show high silica concentrations. These sites are located near schools and horse farms, where increased surface runoff results in more water movement over the soil and bedrock and an increase in silica concentrations. Silica concentrations are least variable in areas where water is supplied by groundwater (BAOC6, and BAOC2). Urbanization has a less immediate effect on groundwater due to limited interaction with surface contaminants. BAOC7 is supplied by groundwater but the anion concentrations are very variable. This is possible due to the site being periodically dry or wet, which results in varying amounts of water level at the site that can dissolve silica from minerals.

The Bunched Arrowhead sites are rich in dissolved carbon dioxide and dissolved organic carbon. Sites are spring or seep fed with minimal time for water to interact with the atmosphere, resulting in increased carbon dioxide concentrations from groundwater sources. Sites with large changes in water flow after storms due to urban runoff (BAOC12, BAOC15) show greater variability in dissolved organic carbon concentrations. Concentrations are greatest in sites that are predominantly groundwater fed (BAOC6, BAOC2, and BAOC7).

Table 2 shows the Bunched Arrowhead sites are rich in dissolved organic nitrogen, nitrate, and nitrite. Sites near areas of increased development and urbanization (BAOC12, and BAOC15) show variable nitrogen concentrations, while sites that are located in areas with the least amount of development (BAOC6 and BAOC13) show more stable nitrogen concentrations. Nitrogen concentrations are the result of atmospheric deposition and from anthropogenic sources, such as fertilizers. BAOC15 shows higher dissolved organic nitrogen concentrations while BAOC12 shows higher nitrate concentrations.

Conclusion

Bunched Arrowhead plants appear to need a stable hydrologic regime since sites with large changes in water chemistry show declining Bunched Arrowhead plant numbers that are yellow-brown in color and small. Sites with stable water chemistry show hundreds of plants that are a vibrant green color that are tall with broad leaves. Increased development increases water flow at the Bunched Arrowhead sites, resulting in greater changes in water chemistry and reduced numbers of Bunched Arrowhead plants for each site. Sites that are near high intensity urban areas show greater variability in water chemistry due to increased water flow that dissolve minerals in the soil. Sites that are in deciduous and evergreen forests show stable water chemistry due to water supplies from groundwater that are not impacted by nearby development. The results show sites with stable water chemistry have a greater proportion of forest cover within the .25 mile buffer, resulting in less urban impact due to containments and changes in water flow within the watershed.

Future Research

Future research could include looking at the impact of urbanization on stage and discharge at each of the six sites in addition to water chemistry. Stage and discharge would be useful to map in order to create a broader hydrologic characterization of each site and to determine if there is a correlation between water flow and volume at the site and in nearby urban areas. The plant does not tolerate hydrologic variability within its habitat, particularly variability in water flow, and it would be interesting to see if there is a correlation between changes in flow rates, stage data, and discharge, urban development and land use. Sites that are heavily impacted by urbanization, such as sites BAOC15, could be protected from further impact by limiting future development at the site and re-engineer water runoff (particularly from homes and industries) to divert flow away from the site.

References

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Data Source: USGS National Land Cover Database 2001.

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