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The Effects of Contrasting Management Scenarios on Ecosystem Service Delivery in Iowa City, Iowa

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Introduction

Ecosystem services are defined as the benefits provided to humans by ecosystems and are economically valuable, though yet not fully understood (Millenium Ecosystem Assessment 2005). Air, water, soil, and organisms all interact in ecosystems and in doing so, benefit society. These benefits include water purification, soil retention, climate regulation, pollination, and goods such as timber, among many others. These services have value, whether it be a direct market value or an avoided cost. Due to this, ecosystems need to be better understood so they can be valued accurately in order to provide their services as efficiently as possible. The economic value assigned to various ecosystem services can help identify adequate trade-offs and management decisions (Abson and Termansen 2009).

One vital service that ecosystems provide is that of carbon storage and sequestration. Ecosystems help regulate climate by removing greenhouse gases, such as CO_2, from the atmosphere. Carbon is stored in wood, other biomass, and soil. Over time carbon is "sequestered," as it accumulates in plants and soil (Natural Captial Project 2015). Development, disturbances, and other land use changes may release this sequestered carbon into the atmosphere (Natural Captial Project 2015). This, combined with emissions from burning fossil fuels, has led to anthropogenic climate change (Natural Captial Project 2015).

A second important ecosystem service is bee pollination. This is valuable and important for the production of goods such as fruits and vegetables, and for sustaining the aesthetics of natural areas and parks (Hanley, et al. 2015). The delivery of pollination as a service depends on the availability of pollinator habitat and flight ability, food resources, and the proximity to crops (Bates, et al. 2011). Pollination is valuable for urban vegetation, as well as surrounding agriculture and natural habitats by increasing yield, quality, and stability of pollinated vegetation (Potter and LeBuhn 2015). Quantity and diversity of pollinators is essential when assessing pollination services, habitat protection, and agricultural vulnerability. Seventy-five percent of globally important crops rely in part of completely on animal pollination (Natural Captial Project 2015). In fact, 87 out of 115 globally important crops benefit from animal pollination (Klein, et al. 2007).

Carbon storage and pollination services are often controlled by land management practices. Different scenarios for these services can be analyzed using the Carbon Storage and Sequestration and the Pollinator Abundance Integrate Valuation of Ecosystem Services and

Tradeoffs (InVEST) models from the Natural Capital Project and Stanford University's Wood Institute for the Environment. The InVEST Carbon Storage and Sequestration model is often used to explore various management scenarios, such as Tomasso et al. where the impact of land use changes was assessed in Connecticut, USA (Tomasso and Leighton 2014). Varying scenarios are also used in the InVEST Pollination Abundance model, as in Keller et al. who explored different scenarios for land management to maximize different ecosystem services (Keller, Fournier and Fox 2015).

The primary objective of this research was to investigate how various management scenarios within the city of Iowa City impact the delivery of both carbon capture and storage and pollinator services, thus offering guidance on how to maximize the services using different management practices. We expected to find that future theoretical management scenarios, which included the expansion of natural areas within city-owned parks, will have a positive effect on service provisioning.

Methodology

Carbon Storage and Sequestration

The InVEST Carbon Storage and Sequestration model from the Natural Capital Project was used to estimate the amount of stored currently in above ground carbon pools within all parks owned by the City of Iowa City. In addition, the amount carbon sequestered over time was estimated using two theoretical management scenarios. The model operates by first estimating the current amount of carbon stored in an area based on a user-provided land use/land cover (LULC) map and a corresponding carbon pool coefficient table. The model then measures the difference in carbon stored between this baseline LULC map and a user-provided future scenario LULC map. A positive difference in storage is referred to as the amount of carbon sequestered within the time frame, whereas a negative value indicates the amount of carbon released into the atmosphere. The model then values the carbon sequestered based upon the current market price of carbon, annual rate of change, and discount rate.

For this study, a 2009 1-meter resolution land use map of Iowa City was obtained from the Iowa Natural Resources Geographic Information System (NRGIS) Library, as also seen in Figure 1 (Iowa Geological and Water Survey 2014). This map used 15 land use classes, 14 of which can be found in the Iowa City area, as seen in Figure 1. In an effort to improve the accuracy of the land use classifications within each park, several adjustments were made using ArcGIS. As there are no agricultural areas within City-owned parks, all pixels deemed as corn, soybeans, or cut hay were reclassified to tall grass, or "Grass 2." Next, the areas deemed wetlands were altered by incorporating a National Wetlands Inventory shapefile, which was also obtained from the NRGIS Library (Iowa Geological and Water Survey 2014). This was added to the land use raster by first using the Polygon to Raster Tool and then mosaicking the two rasters together. The updated land use map can be seen in Figure 2. A shapefile containing all parks was obtained from the Iowa GIS Data Repository and was filtered to only include those parks owned by the City of Iowa City, as seen in Figure 3 (Iowa Counties Information Technology Association 2015). Future land use scenarios were constructed using ArcGIS. The reclassify tool was first used to change all land uses within parks other than pavement and water to forest, as seen in Figure 4. Next, the same tool was used to change all land uses other than forest, pavement, and water to tall grass, referred to as "Grass 2," as seen in Figure 5. These theoretical future scenarios were set to be accomplished by 2020.

The carbon pool coefficient table values were obtained from Chang Zhao, a Ph.D. candidate within the University of Iowa Department of Geographical and Sustainability Sciences. Zhao was able to determine above ground carbon coefficients for Iowa City from the US Forest Service's forest biomass estimates using zonal statistics (Zhao 2015). This can be seen in Table 1. The current market value of carbon dioxide equivalent, $12.89 per metric ton, was obtained from the California Carbon Dashboard (Climate Policy Initiative 2015). The social value of carbon per metric ton was then found by multiplying the market value by 3.67, as outlined in the InVEST user's guide (Natural Captial Project 2015). This yielded a result of $47.31 per metric ton. The market discount in price of carbon was left at the model default value of 7%, as recommended by the InVEST User's Manual (Natural Captial Project 2015). The annual rate of change in the price of carbon was held constant by setting the value to 0%, assuming that the value of sequestered carbon did not change.

Pollinator Abundance

The InVEST Pollination Abundance model, also from the Natural Capital project, was used to estimate bee pollinator abundance in all areas within a 500-meter buffer around Iowa City. This model uses several inputs including a current and future land use map, a land cover attributes table, and a pollinator guild table to estimate pollinator nesting sites, floral resources, and flight ranges. The model estimates the abundance of each species in each cell of the map by using the available nesting sites along with the available flowers in the surrounding cells (Natural Captial Project 2015). The resulting output is expressed as the "pollinator abundance index," which indicates "the likely abundance of pollinator species nesting on each cell in the landscape, given the availability of nesting sites and of flower (food) resources nearby," (Natural Captial Project 2015).

The baseline land use map developed for the Carbon model was reused for the Pollination model, except for one additional step which mosaicked the updated park land use and the Iowa City area land use maps together (Figure 2). Both the forest and tall grass future management scenarios from the carbon model were also reused (Figures 13 and 14). In addition, a third scenario where the parks were changed to be completely developed except for water was included (Figure 15. To improve processing time, the resolution of all raster inputs was resampled from 1 meter to 5 meters. The model requires a user-provided land cover attribute table which assigns a value from 0 to 1 based on the ability of each land use to provide nesting habitat and floral resources. These values were provided by Dr. Stephen Hendrix, Professor Emeritus from the University of Iowa Biology Department, as seen in Table 4 (Hendrix 2015).

The species guild table consisted species/guild names, nesting availability, be it cavity or ground, of each pollinator, pollinator activity by floral season, and average foraging distance based on body length by measuring the distance between the wing bases, intertegular (IT) span (Table 4) (Greenleaf, Williams and Kremen 2007). Which species to include and all table coefficients were also provided by Dr. Hendrix, as seen in Table 5 (Hendrix 2015). These species represent about one-third of the total abundance of the Iowa City bee species collection and were chosen for their range in nesting habitat, body size, and seasonal activities (Hendrix 2015). At Dr. Hendrix's suggestion, the model was run first with four species, then again with all eight species. This provided the ability to examine whether biodiversity in pollinators made a difference in the pollinator nesting abundance (Hendrix 2015).

The flight distance of each bee species was calculated using the logarithmic formula *log(distance) = log a + b log IT*, which relates each species' integer length (IT length) to its foraging distance where *a* is a constant and *b* is the exponent for type of distance measured (Greenleaf, Williams and Kremen 2007). For the purpose of our study, which was to calculate maximum homing distance, we used *log a* equal to -1.363 and *b* equal to 3.366. The results of these calculations can be seen in Table 5.

Results

Carbon Storage and Sequestration

For the 2020 forest scenario, carbon storage increased in areas where forests were added, as seen in Figures 6 and 7. By increasing forest extent, the amount of carbon stored moved from a total of 12,444.86 metric tons of carbon in the baseline scenario to 27,013.67 metric tons of carbon in the future forest scenario (Table 2). This accounted for a positive net change of 14,568.82 metric tons of carbon sequestered, which translates to a value of $488,143.10, based upon the avoided societal cost of carbon otherwise released into the atmosphere (Table 2 and Figures 8 and 9). As seen in Figures 6 and 10, there was little difference between the baseline map and the 2020 tall grass scenario. This change in land use only accounted for a total of 1.22 metric tons of carbon sequestered, translating to a value of a mere $41.99 (Table 2 and Figures 11 and 12).

Pollinator Abundance

Increasing the number of bee pollinators from four to eight, and thereby accounting for increased biodiversity, did not have a spatial impact on pollinator abundance. However, increased biodiversity did result in an increase of the likelihood of abundance of pollinator species from a under 0.60 to over 0.65 in each cell of the landscape, as seen in Table 6 and Figures 16 and 17.

Both forest scenarios increased the area of bee pollinator nesting abundance, as seen in Figures 18 and 19, but the maximum likelihood of abundance per cell in the landscape remained the same as the likelihood of abundance per cell in the current land cover landscape (Table 6). When the model was run using the tall grass scenarios, there was an increase not only in the amount of areas with high likelihood of pollinator nesting abundance, but also in the maximum pollinator abundance per cell (Figures 20 and 21). Both tall grass scenarios also had a higher maximum abundance than non-tall grass scenarios, as seen in Table 6. The development scenarios both resulted in zero likely abundance of pollinator species nesting in these areas

(Figures 22 and 23). This conversion also decreased the likelihood of pollinator species nesting abundance in the areas surrounding the city parks.

Discussion

Carbon Storage and Sequestration

As expected, the future scenario in which forests were expanded increased the amount of carbon stored dramatically. While this scenario is an extreme example, any expansion of forest should drastically increase the amount of carbon stored. The tall grass scenario accounted for a minimal increase in carbon storage. This was due to the fact that much of the LULC conversion to tall grass, or "Grass 2," was from turf grass, or "Grass 1," (Figure 2). As seen in Table 1, the coefficients for Grass 1 and Grass 2 are identical, and thus resulted in no increase in carbon storage. If the turf grass had been changed to an additional prairie LULC class, the aboveground biomass would have greatly increased (Dietzel and Jarchow 2015). Further research should attempt to also include additional carbon pools (belowground biomass, soil, and dead organic matter). This would dramatically impact the results, as seen Dietzel and Jarchow, who determined that significant biomass is stored belowground in areas of prairie in Boone, IA (Dietzel and Jarchow 2015). Future studies could explore more practical land use management plans rather than the extreme scenarios included in this study. Such a study would be beneficial for decision makers when deciding between differing management scenarios. Finally, future studies could also include additional LULC classes to improve the accuracy of model results.

Pollinator Abundance

The three scenarios that were analyzed for pollinator abundance were also exaggerated, but provided a baseline for land management relating to pollination services. As expected, changing land cover to developed land resulted in a pollinator abundance index of zero within these areas, but it also affected the surrounding pollinator nesting areas. This likely reduced the supply for pollination services in the area. The conversion to complete forest cover of the city parks did not produce a change in the maximum pollinator abundance index per cell, but increased the pollinator abundance index in surrounding areas, augmenting the provision of the pollinator service. Increasing the coverage of tall grass in the landscape amplified the maximum pollinator abundance index per cell, which should result in an increase of the service provided by bee pollinators. Running the model with additional bee guilds to account for biodiversity also improved the pollinator abundance index, which signals that increased biodiversity is beneficial to the provision of this service. Future studies could include additional areas where tall grass could be introduced, such as Iowa City roadside grassland that could provide potential nesting sites. Restored native plants in roadsides support greater bee abundance and high species richness (Hopwood 2008). In addition, a scenario where a conversion of landscape to tall grass prairie could give more insight on the provision of pollinator services. Pollinator diversity is influenced by resources availability, in prairie in particular, more than by site characteristics (Hines and Hendrix 2005).

Conclusion

It is recommended that Iowa City should expand natural areas, especially forest, in an effort to add additional carbon storage and mitigate climate change. This should be balanced with expanding areas of tall grass to maximize pollinator abundance. Because food resources for bee pollinators are so dependent on the season, complimentary habitat use, the use of different habitat at different times during their activity period, is important to consider in management (Mandelik, et al. 2012). This supports a need for diverse land uses within City-owned parks. While additional forest coverage would not increase pollinator nesting abundance, it is still necessary for pollination services and is essential for an increase in carbon storage and sequestration. In addition, new community gardens sponsored by the City should be placed near areas of tall grass to benefit from the increased pollinator abundance.

While such management strategies would maximize these services, it is paramount that current natural areas within parks be protected from development to ensure that these services are not lost. Expanding park areas and purchasing additional parks would also be beneficial in ensuring the continued provisioning of carbon storage and sequestration and pollinator services into the future.

Figures and Tables

Table 1 – Iowa City LULC classes and corresponding carbon pool coefficients. (Zhao 2015)

Land Use/ Land Cover	**Above Ground Carbon (Metric Tons of C/ha)**
Open water	0
Wetlands	7.6
Deciduous Short	50.9
Deciduous Medium	49.5
Deciduous Tall	48.4
Grass 1	4.5
Grass 2	4.5
Cut Hay	5.1
Corn	5.1
Soybeans	5.1
Barren / Fallow	1
Structures	0
Roads/Impervious	0
Shadow/No Data	0

Table 2- Results from Carbon Storage and Sequestration Model

Scenario	**Total Carbon (Metric tons of carbon)**	**Sequestered carbon (Metric tons of carbon)**
Current	12,444.86	N/A
Forest 2020	27,013.67	14,568.82
Tall Grass 2020	12,446.07	1.22

Table 3 – Results from valuation of Carbon Sequestration

Scenario	**Sequestered Carbon (Metric tons of carbon)**	**Net Present Value (USD)**

Forest 2020	14,568.82	$502,750.84
Tall Grass 2020	1.22	$41.99

Table 4 – Land cover attribute table, Pollinator Abundance Model (Hendrix 2015)

LULC	Description	LULC Group	Nesting: Cavity	Nesting: Ground	Flight Season: April-May	Flight Season: June-July	Flight Season: Aug-Sept
1	Water	Water	0	0	0	0	0
2	Wetland	Water	0.2	0	0	0.5	0.2
3	Coriferous forest	Forest	0.3	0.3	0.2	0	0
4	Decidous short	Forest	0.7	0.7	0.3	0.2	0.2
5	Decidous medium	Forest	0.5	0.5	0.3	0.2	0.2
6	Decidous tall	Forest	0.2	0.2	0.3	0.2	0.2
7	Grassland 1	Unkn	0	0.5	0.2	0.2	0.2
8	Grassland 2	Unkn	1	1	0.2	1	0.7
9	Cut hay	Ag	0.5	0.7	0.1	0.5	0.3
10	Corn	Ag	0	0.3	0.1	0.1	0.1
11	Soybeans	Ag	0	0.3	0.1	0.1	0.1
12	Barren/fallow	Ag	0.5	1	0.2	0.5	0.3
13	Structures	Built	0	0	0	0	0
14	Roads	Built	0	0	0	0	0
15	Shadow/no data	Unkn	0	0	0	0	0

Table 5 – Species Guild Table, Pollinator Abundance Model (Hendrix 2015)

Species	NS_cavity	NS_ground	FS_April-May	FS_June-July	FS_Aug-Sept	Body Length (IT)	Distance (meters)
Bombus griseocollis	1	0	0	1	0.5	4.16	5258.58
Lasioglossum (Dialictus) prunosium	0	1	0.7	1	0	1.22	84.66
Halictus ligatus	0	1	0.2	1	0.5	1.44	147.93
Andrena wilkelli	0	1	0	1	0	2.23	644.75
Bombus impatiens	1	0	0	0.6	1	3.7	3544.60
Lasioglossum (Dialictus) rohweri	0	1	0.6	1	0.1	1.16	71.44
Halictus confusus	0	1	0.9	1	0.2	1.44	147.93
Andrena zizia	0	1	0.7	1	0	1.34	116.10

Table 4 – Results, Pollinator Abundance Model

Number of Species	Scenario	Maximum Pollinator Abundance
4	Current	0.5838
4	Forest	0.5838
4	Grass	0.5984
4	Development	0.5823
8	Current	0.6767
8	Forest	0.6767
8	Grass	0.6844
8	Development	0.6742

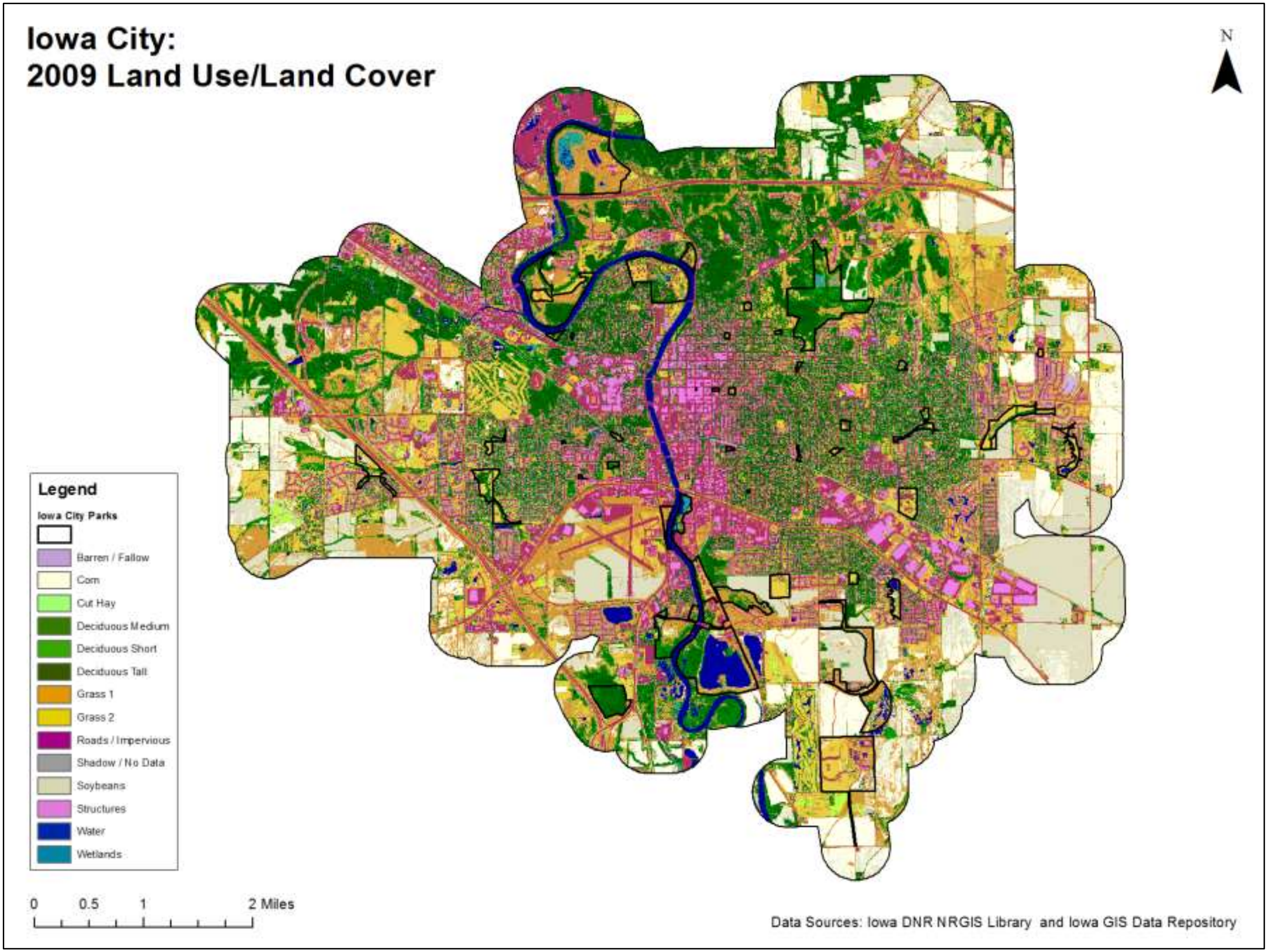

Figure 1 – 2009 LULC from the Iowa Department of Natural Reosurces, within a 500 m buffer of Iowa City.

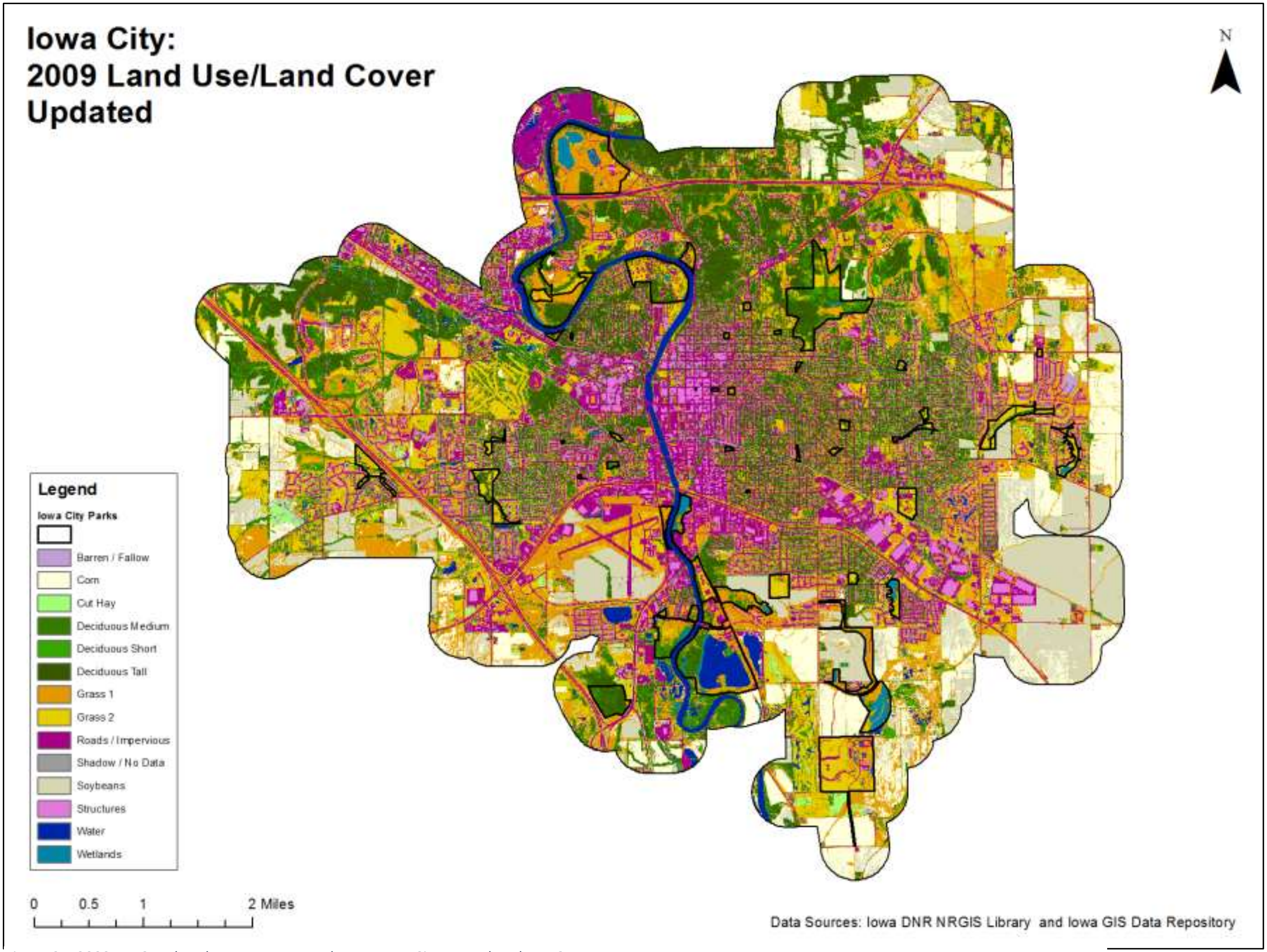

Figure 2 – 2009 LULC updated to more accurately represent City-owned park LULC.

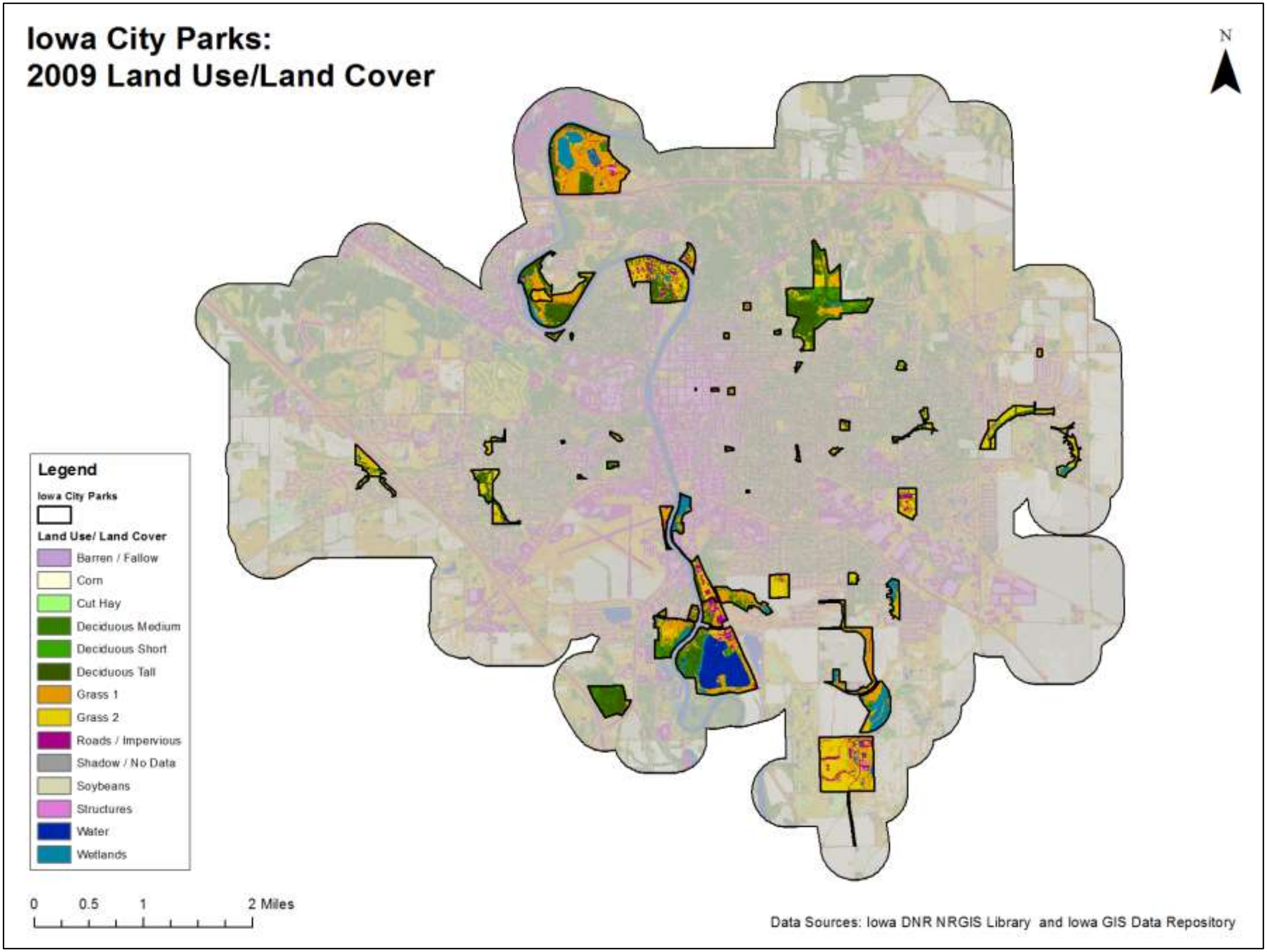

Figure 3 – Baseline LULC map for Carbon Stored and Sequestration model.

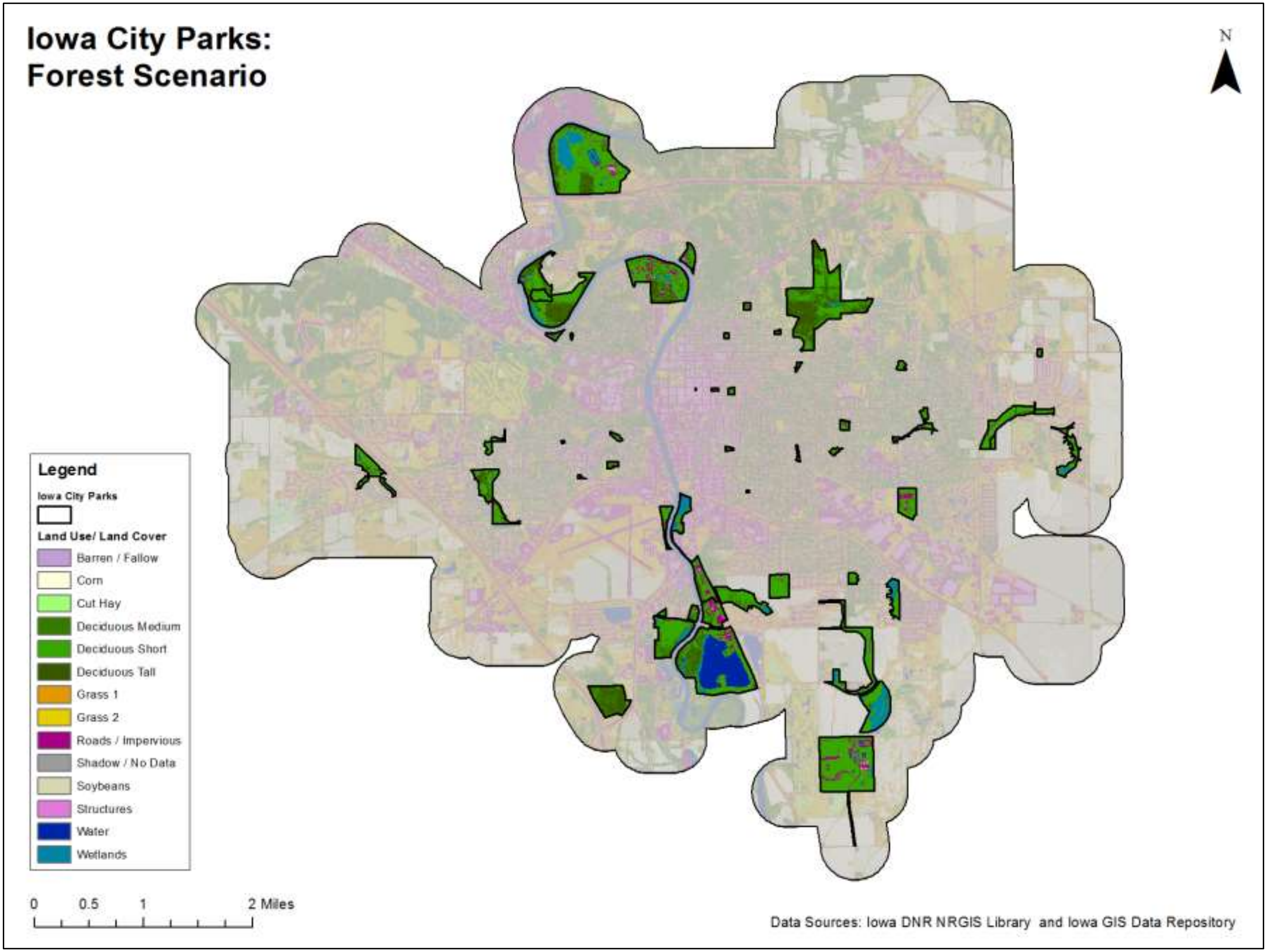

Figure 4 – Forest scenario LULC map for Carbon Stored and Sequestration model.

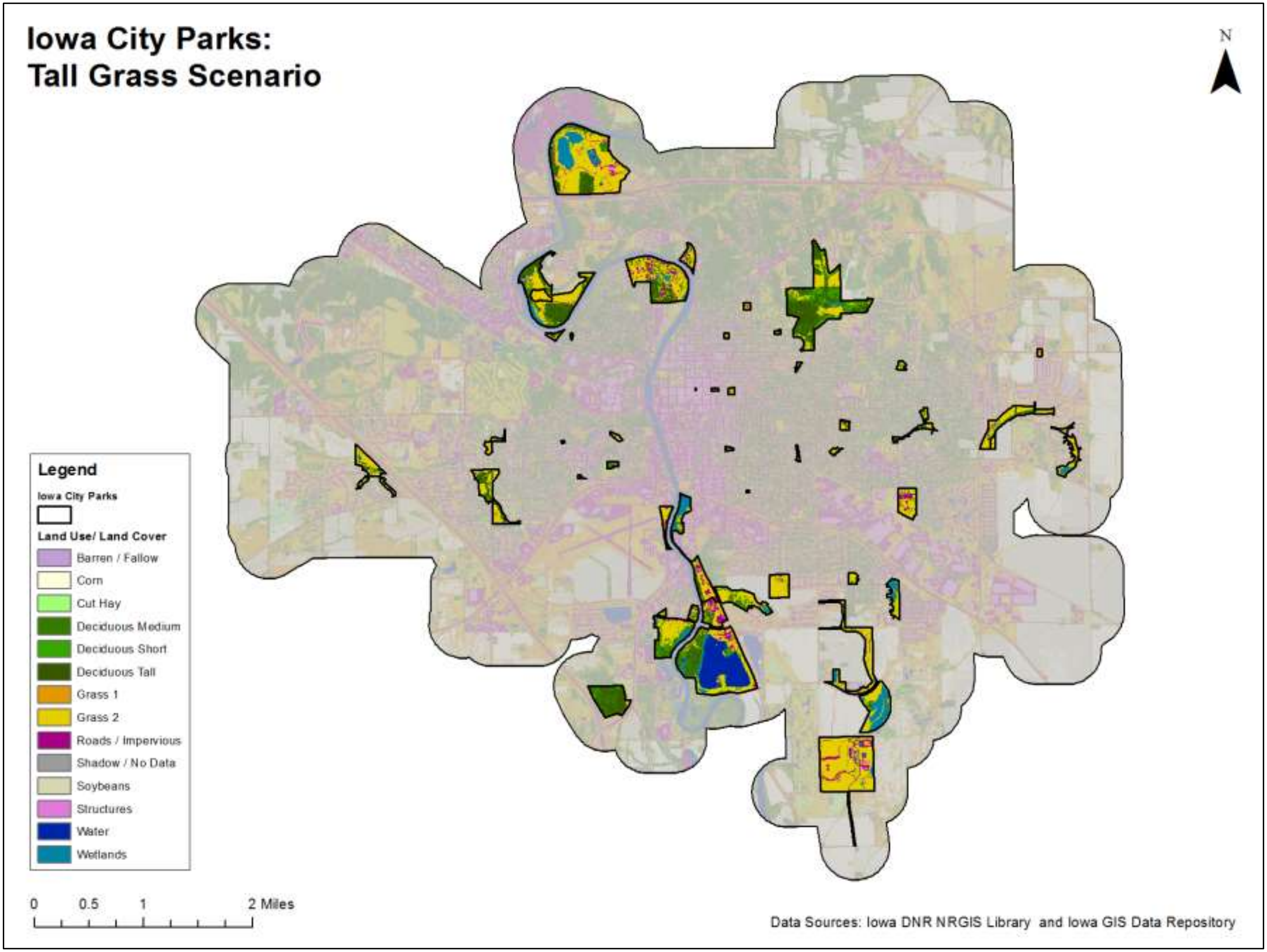

Figure 5 – Tall grass scenario LULC map for Carbon Stored and Sequestration model.

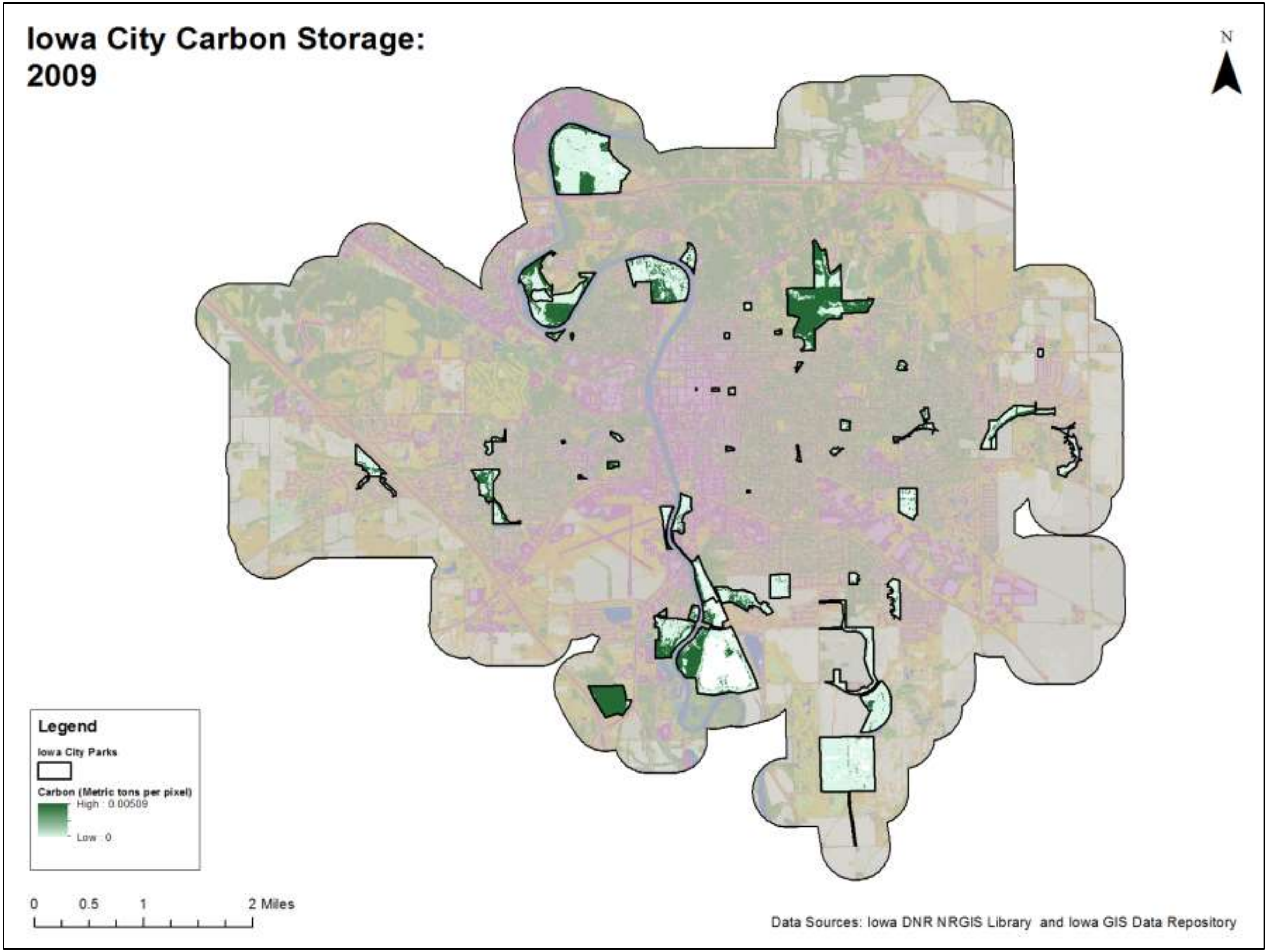

Figure 6 – Baseline carbon storage.

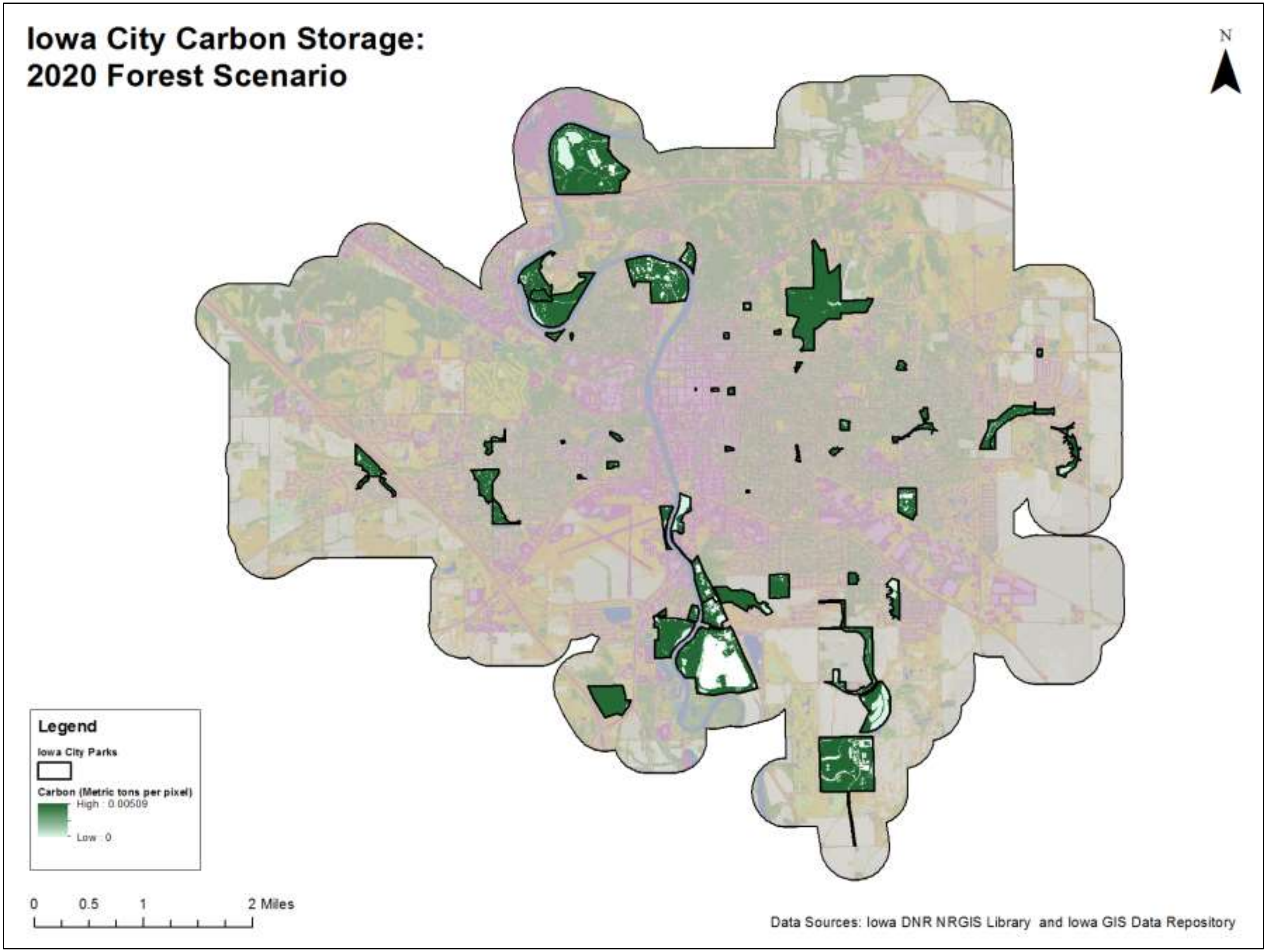

Figure 7 – Carbon storage for 2020 forest scenario.

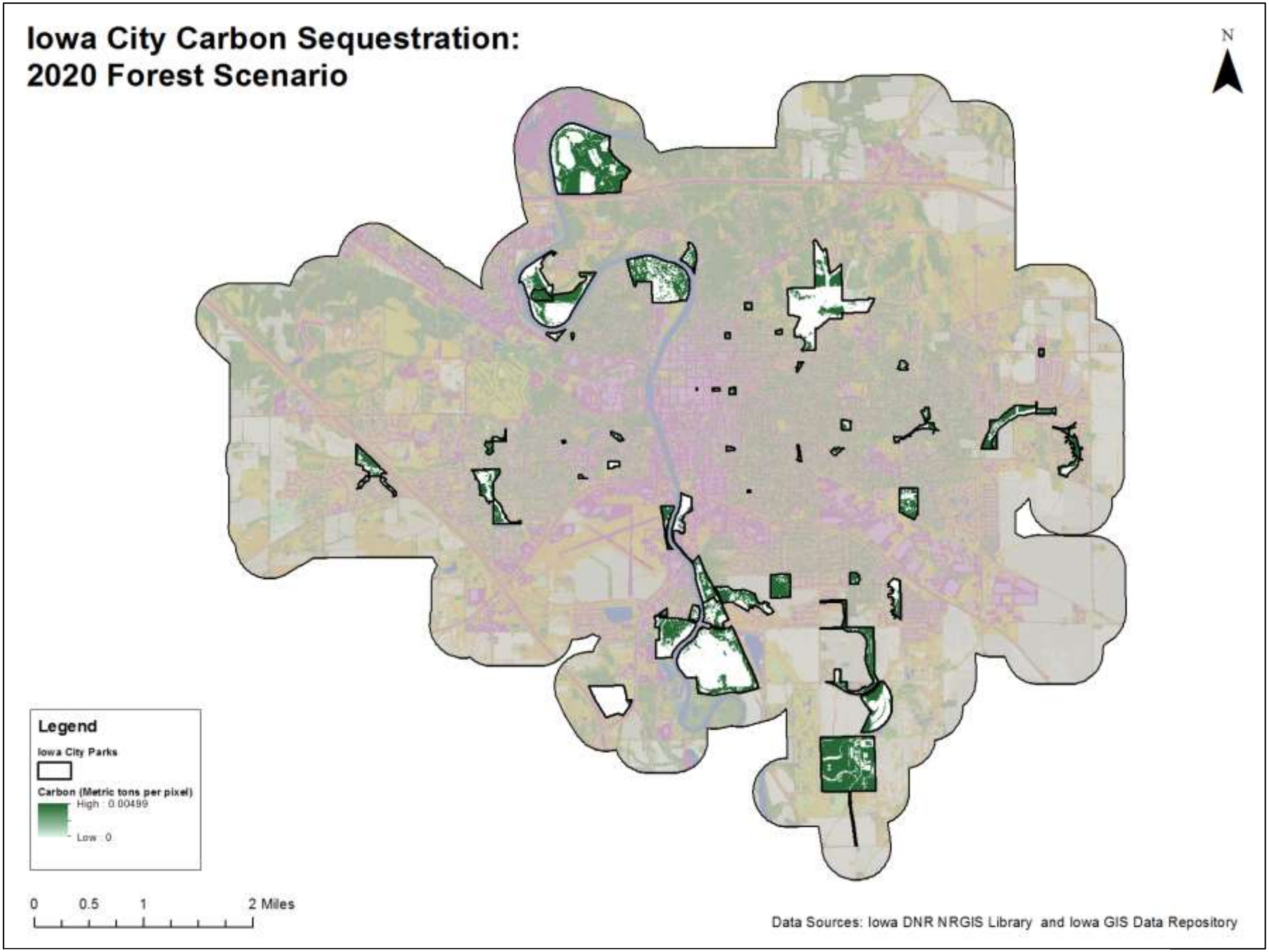

Figure 8 - Carbon sequestrion for 2020 forest scenario. Difference in storage between baseline and future scenarios

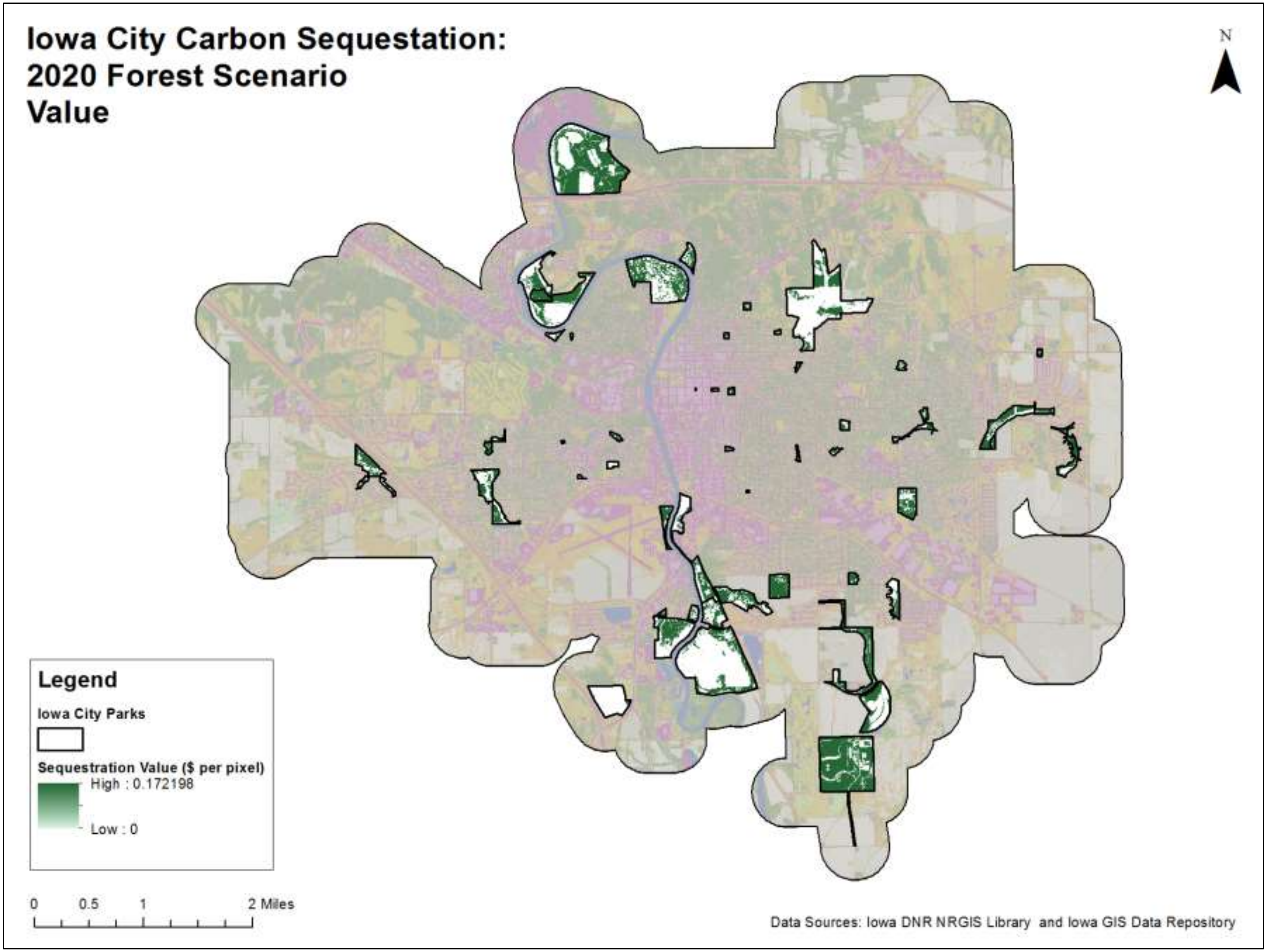

Figure 9 – Value of carbon sequestation across space, 2020 forest scenario.

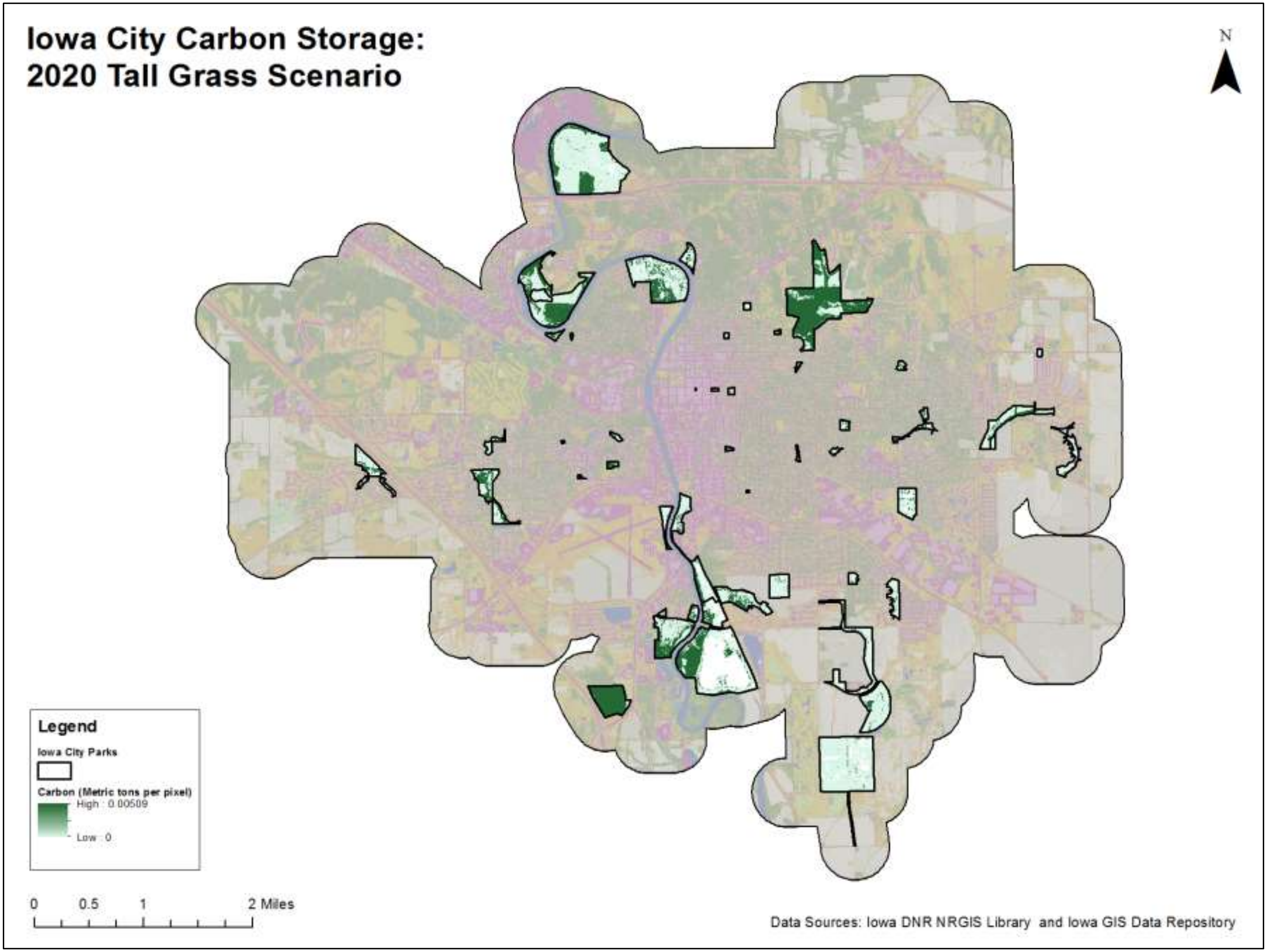

Figure 10 - Carbon storage for 2020 tall grass scenario.

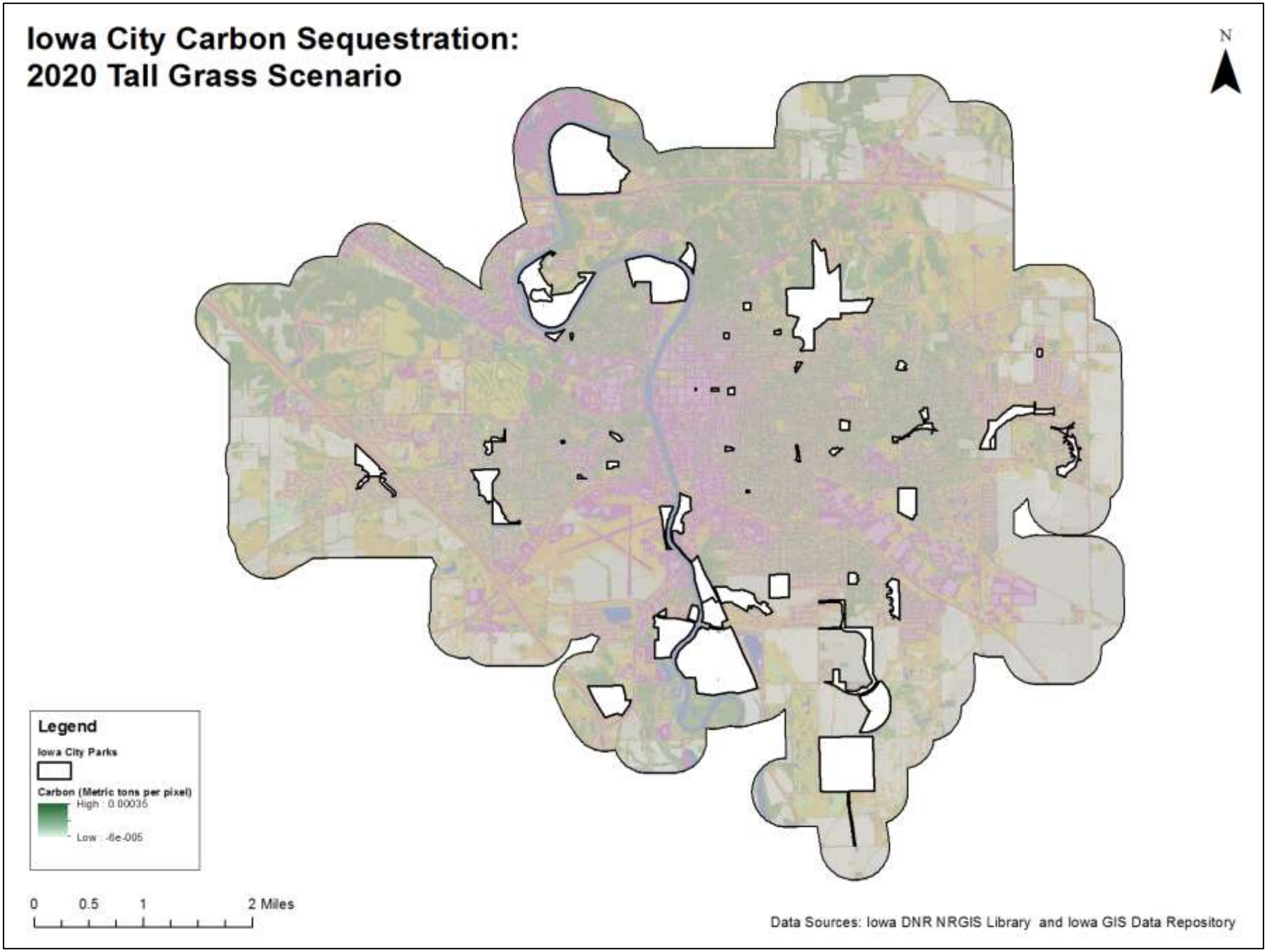

Figure 11 - Carbon sequestrion for 2020 tall grass scenario. Difference in storage between baseline and future scenarios.

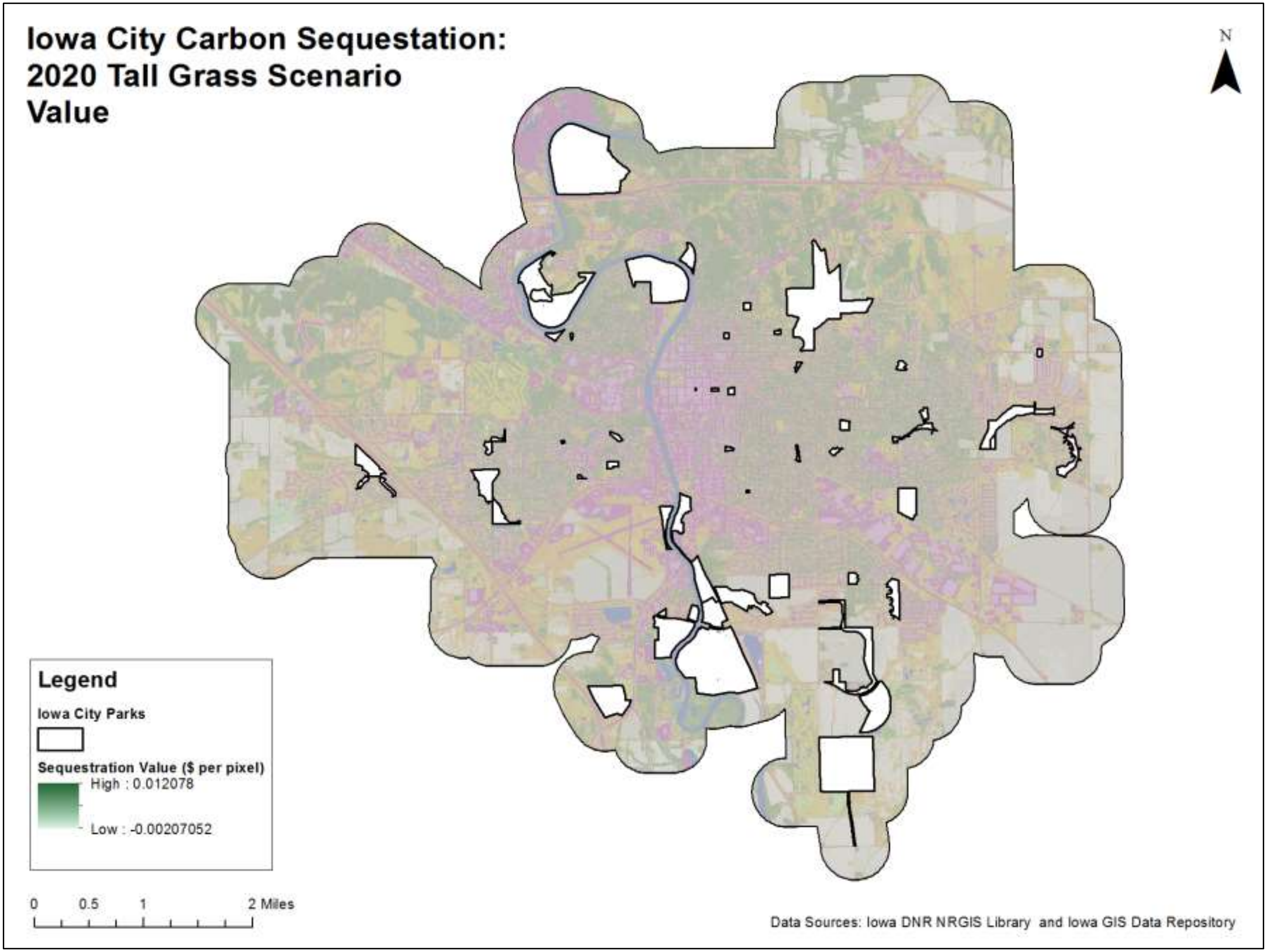

Figure 12 - Value of carbon sequestation across space, 2020 tall grass scenario.

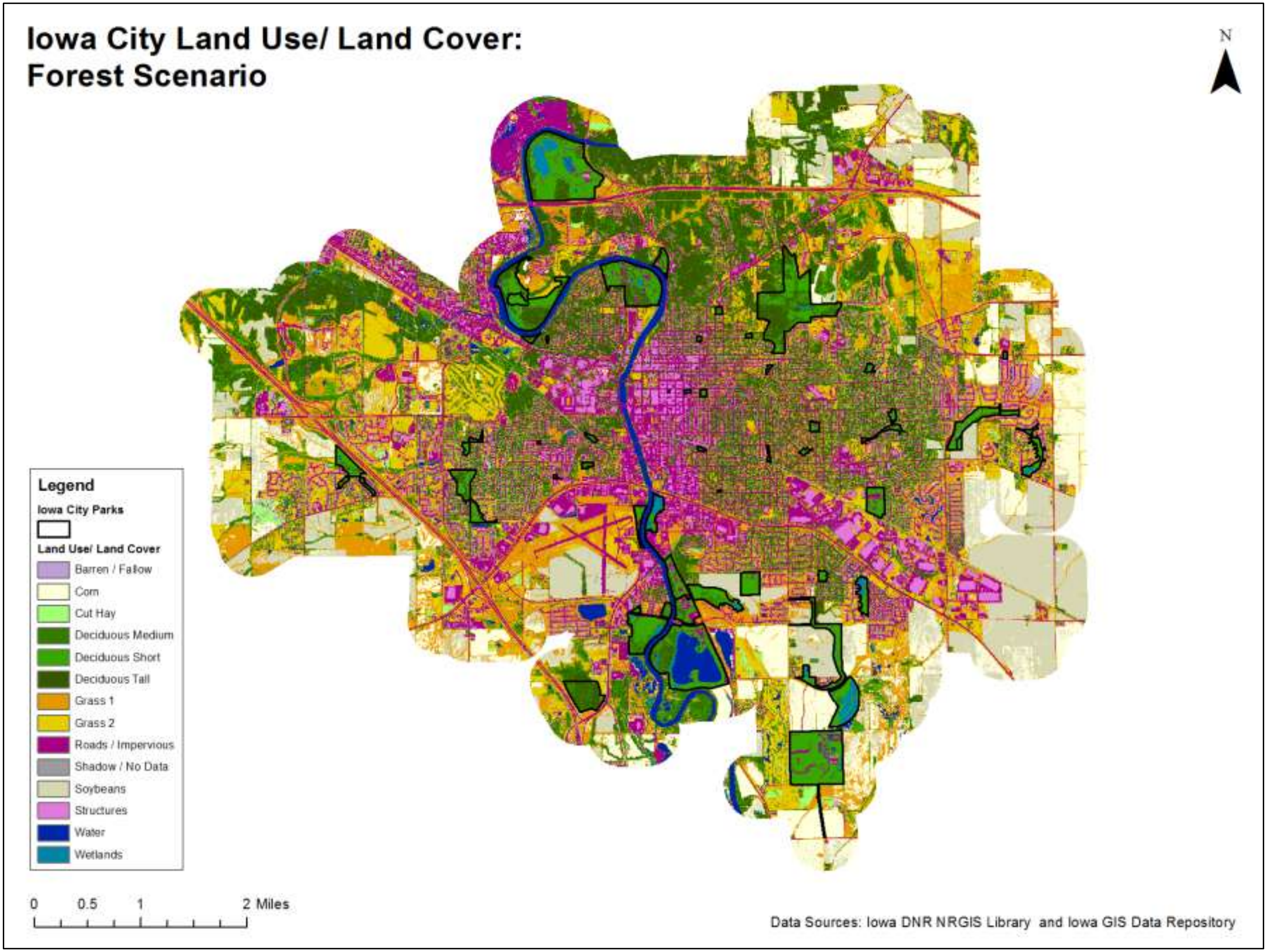

Figure 13 – Forest Scenario, Pollinator Abundance Model

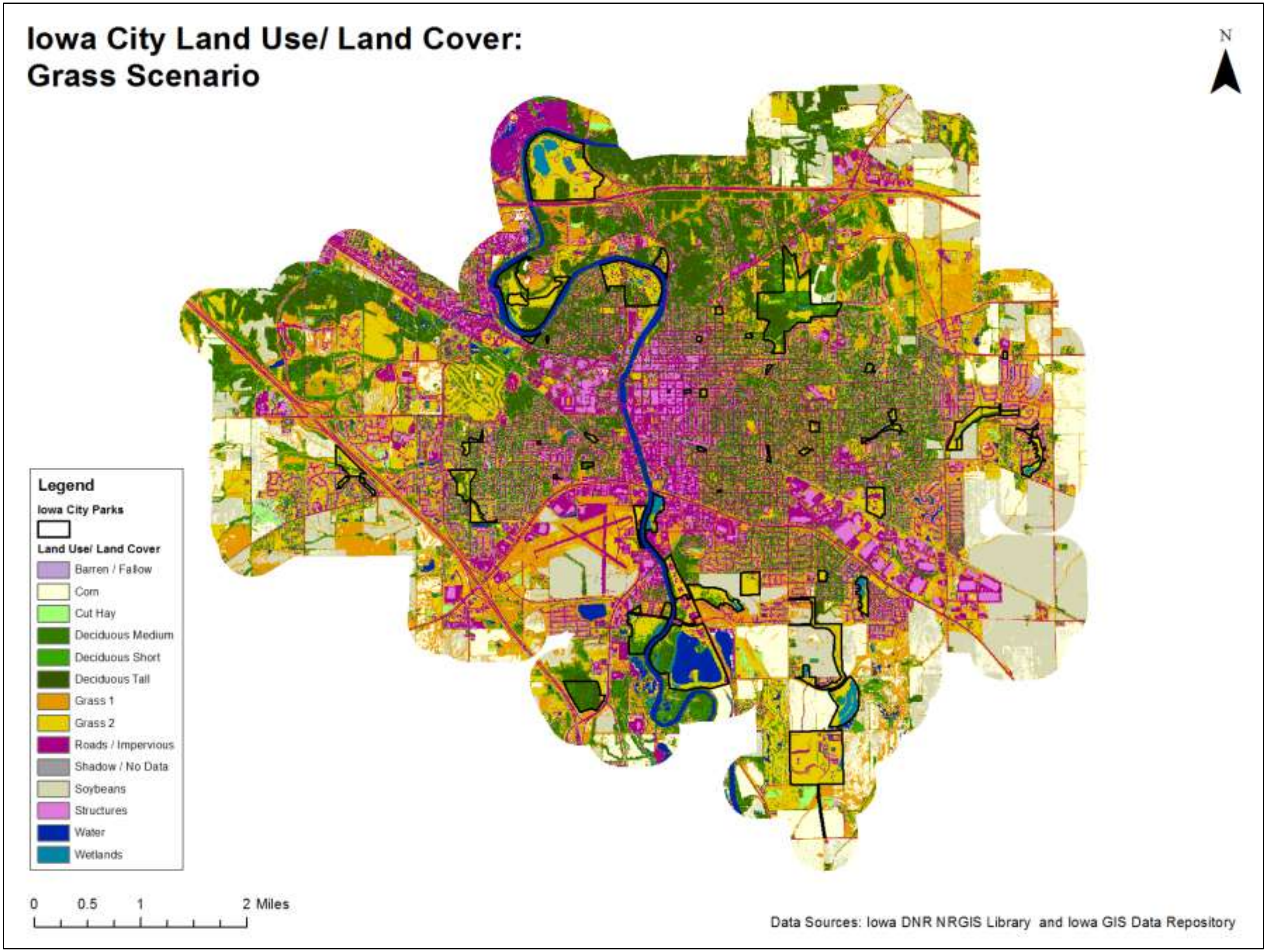

Figure 14 – Tall Grass Scenario, Pollinator Abundance Model

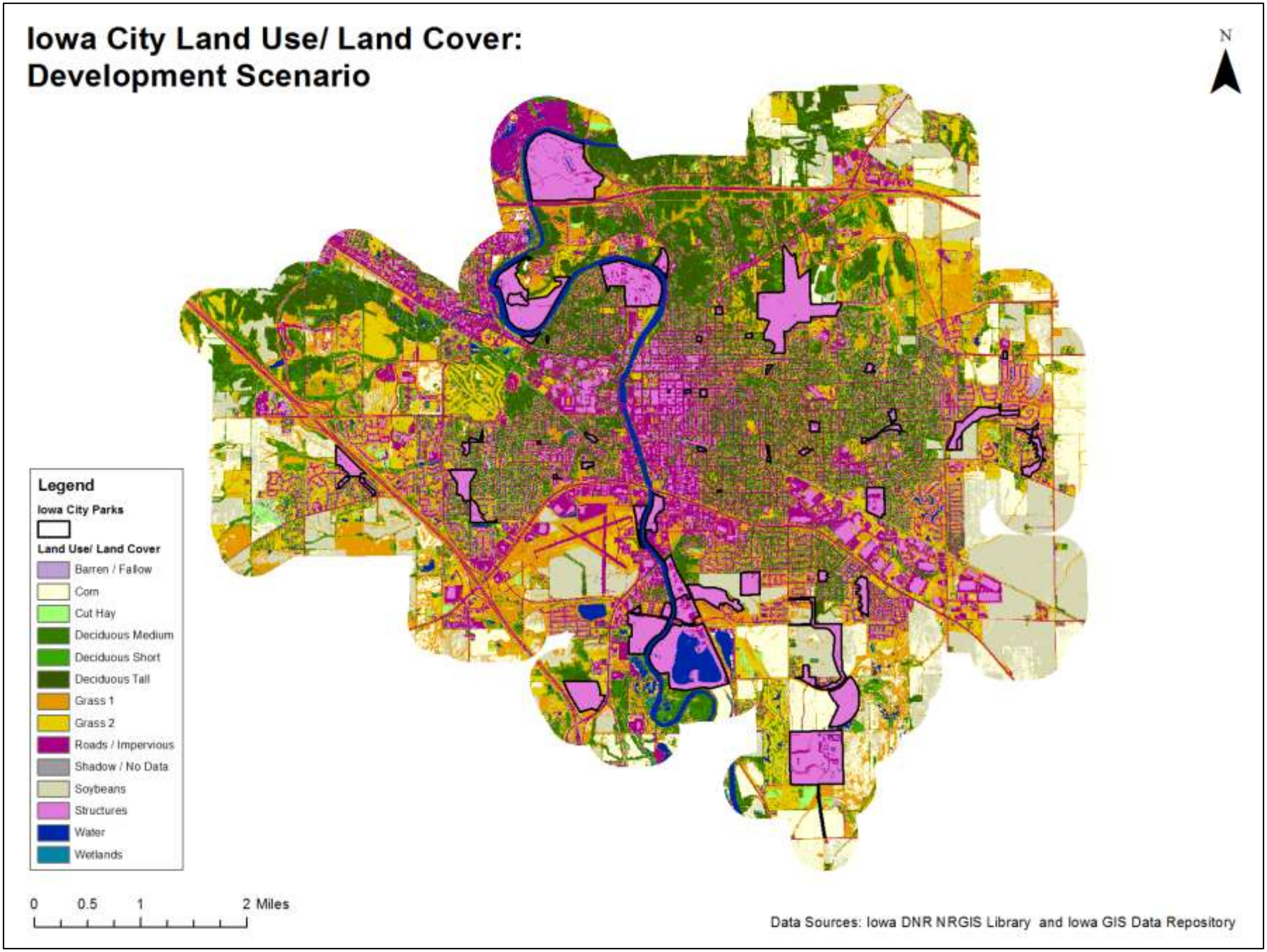

Figure 15 - Development Scenario, Pollinator Abundance Model

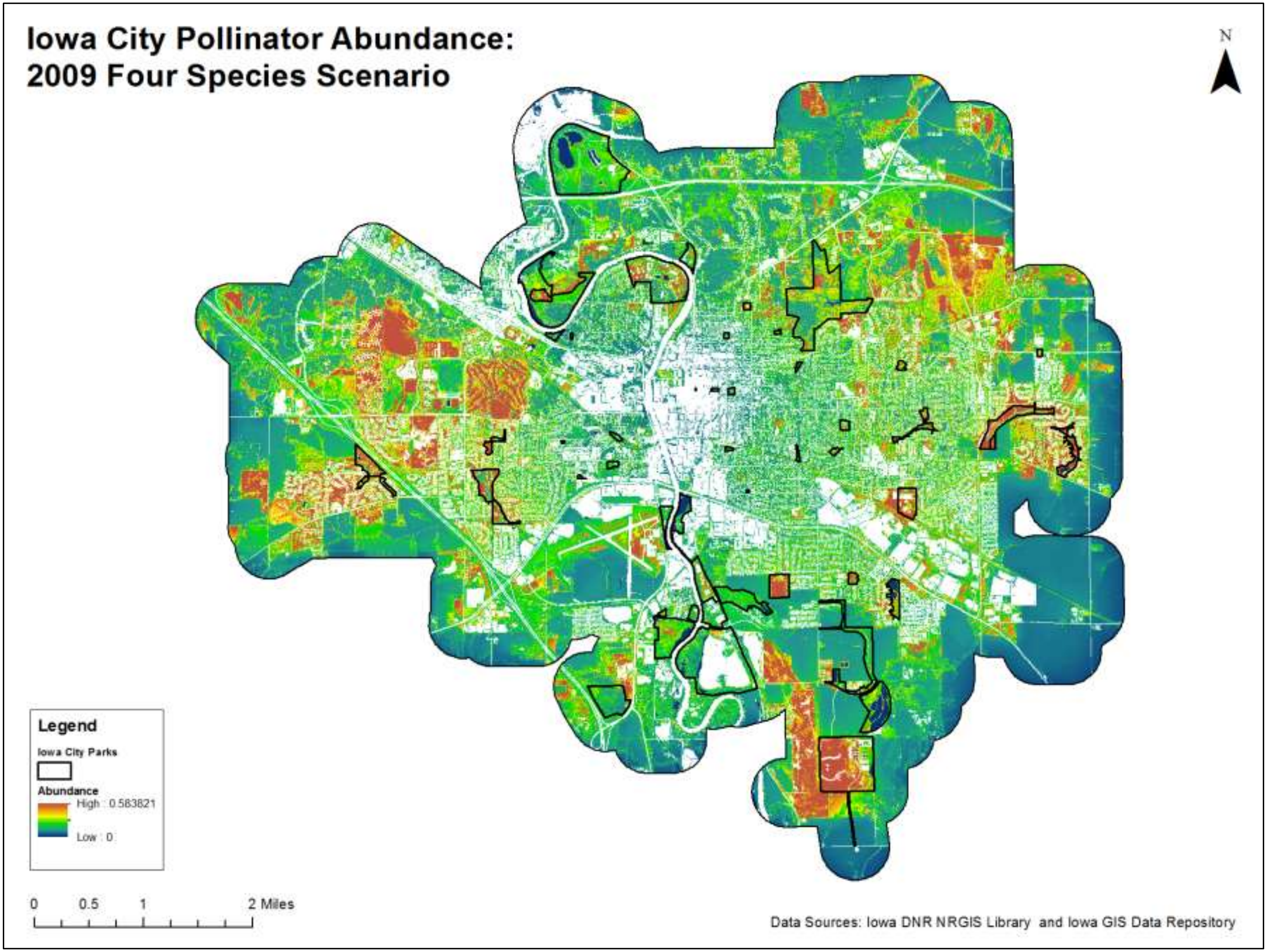

Figure 16 – Baseline pollinator abundance, four species scenario.

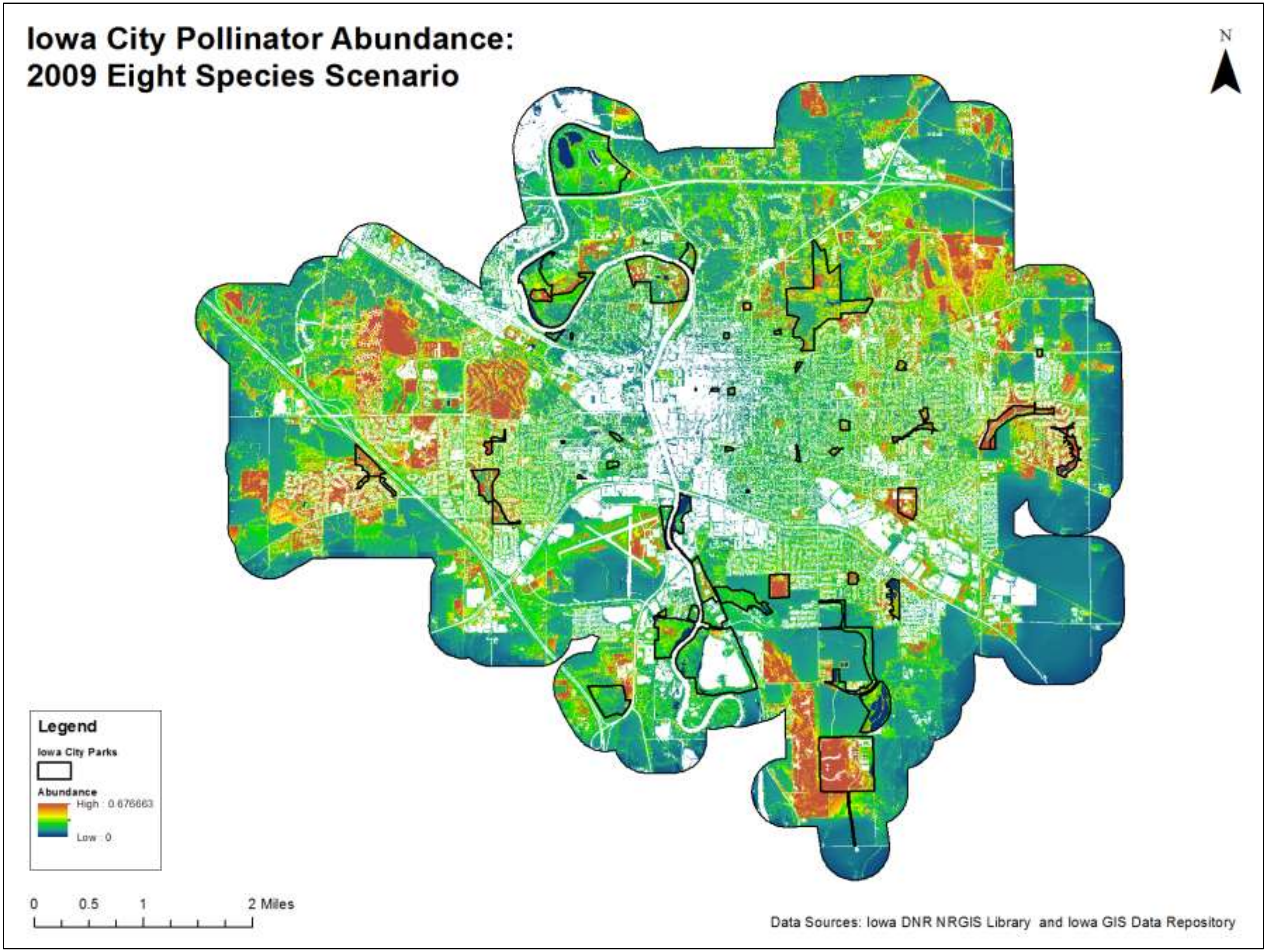

Figure 17 - Baseline pollinator abundance, eight species scenario.

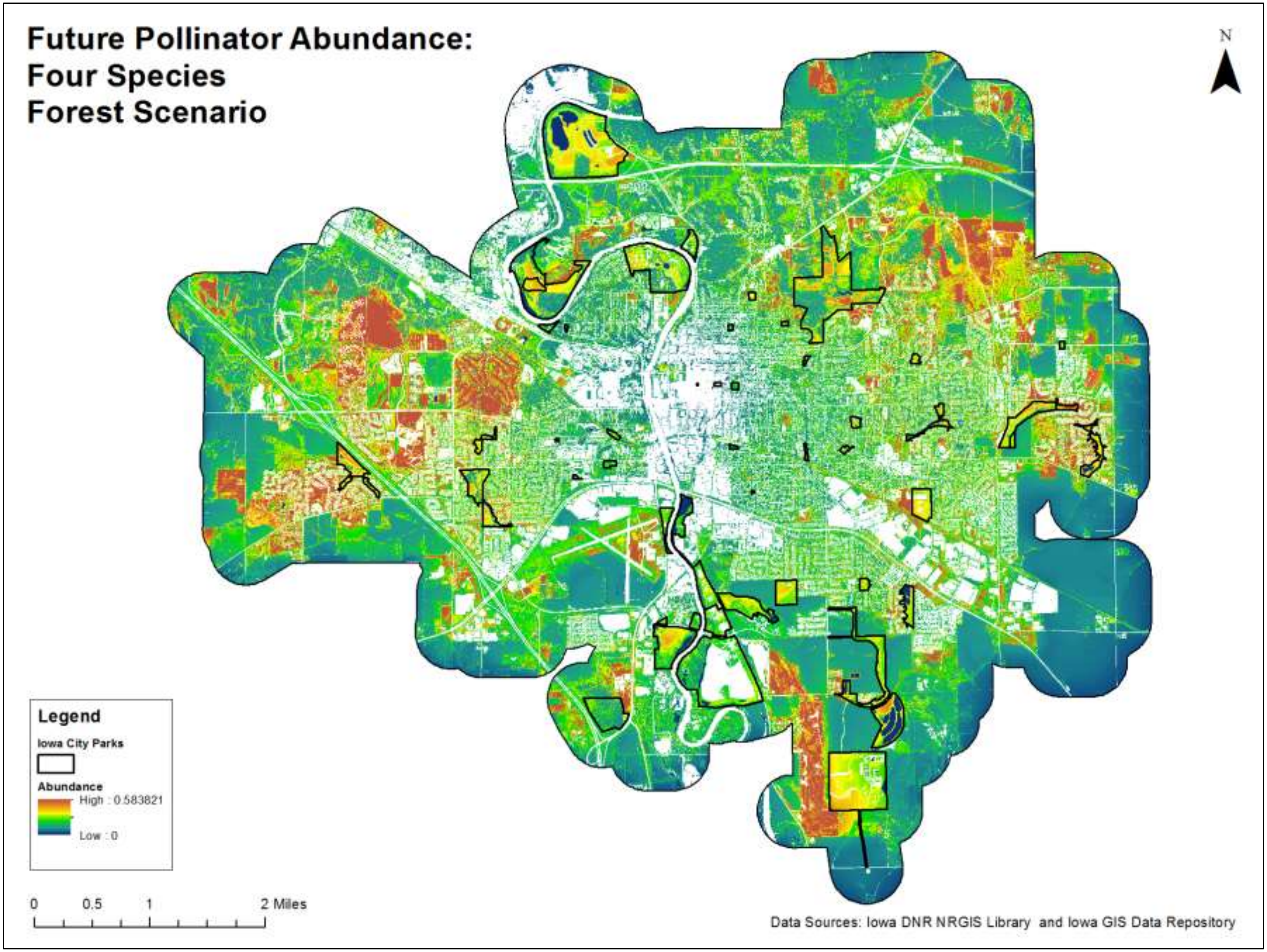

Figure 18 – Future pollinator abundance, forest/four species scenario.

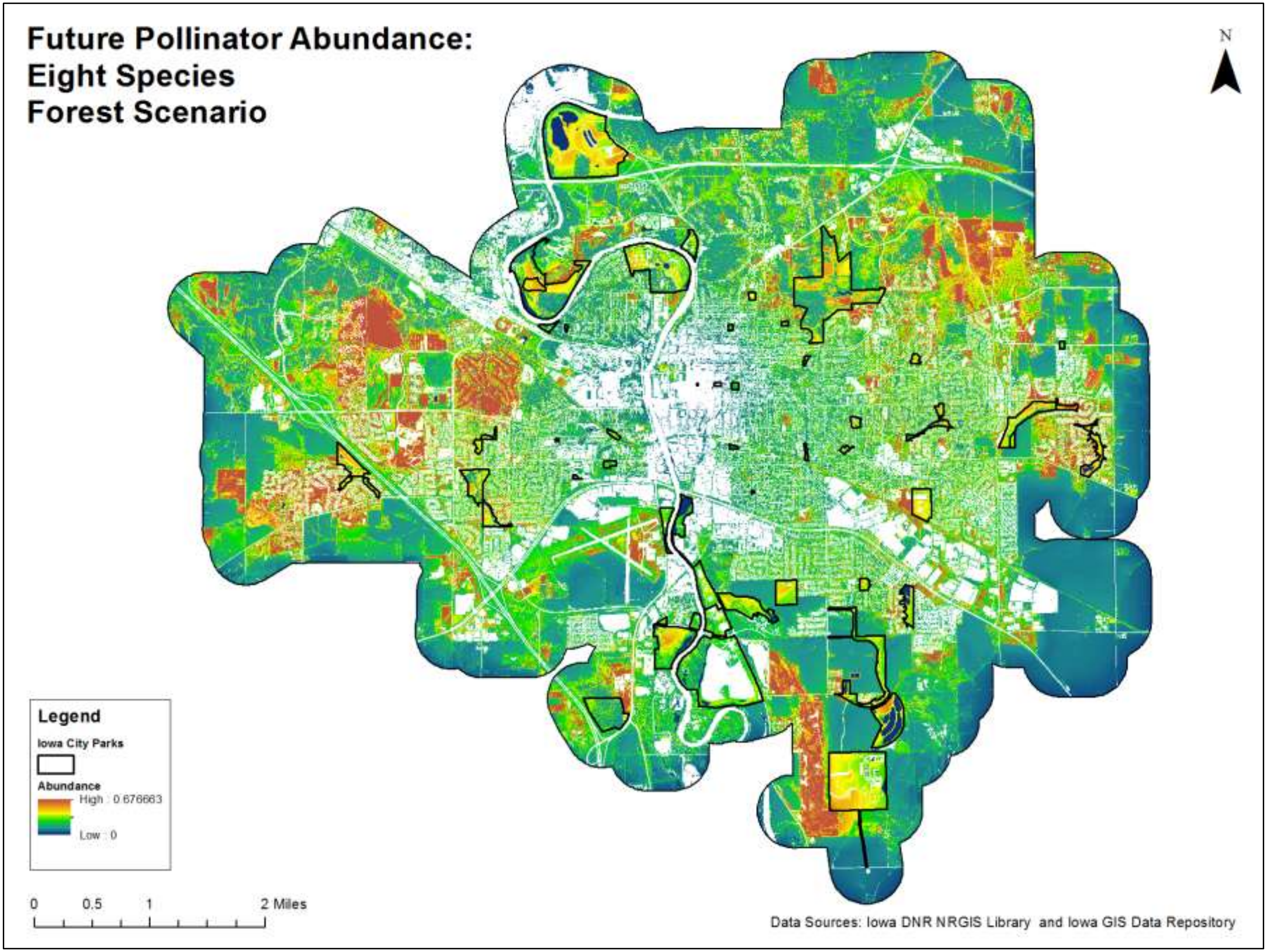

Figure 19 - Future pollinator abundance, forest/eight species scenario.

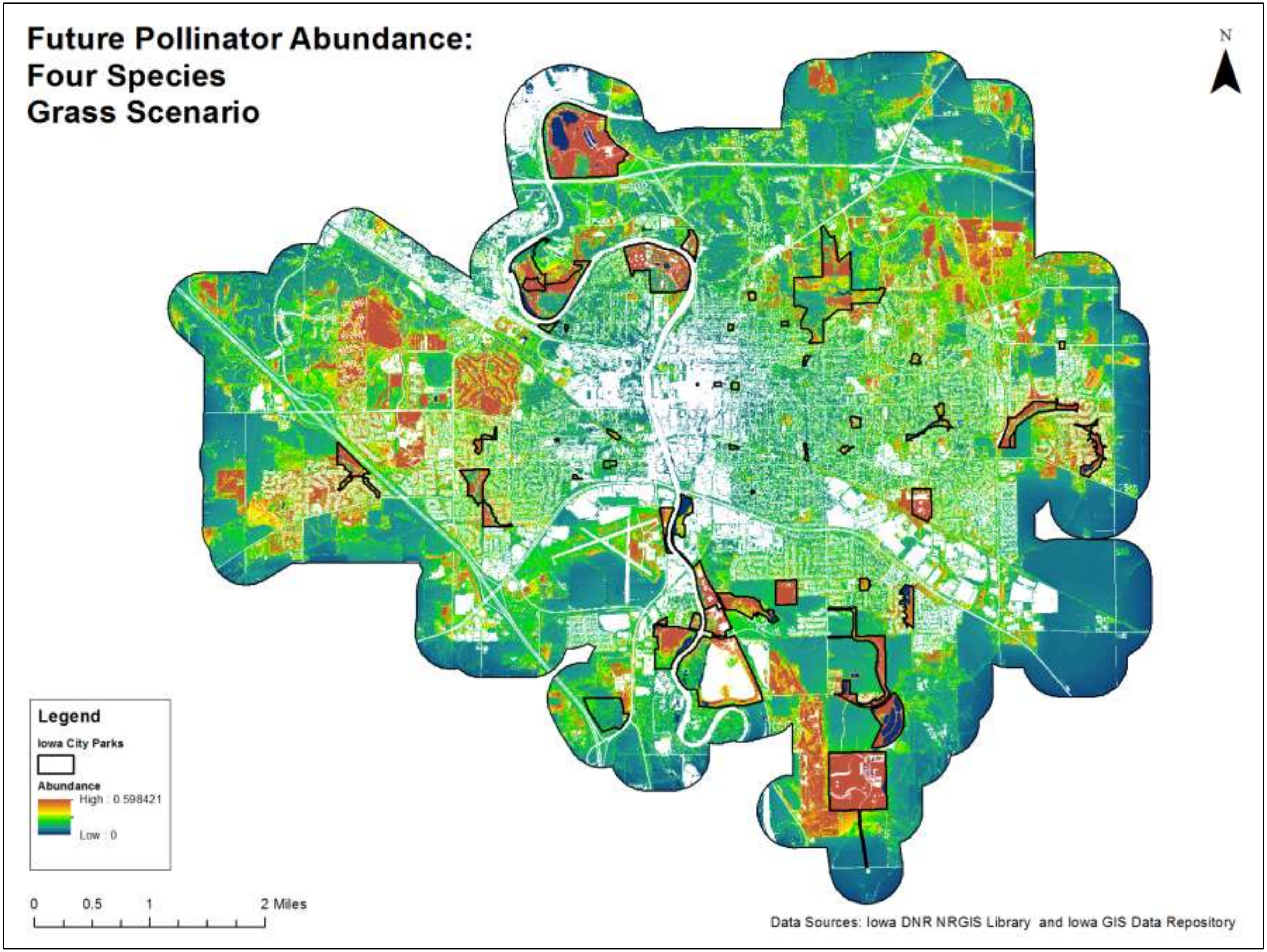

Figure 20 – Future pollinator abundance, tall grass/four species scenario.

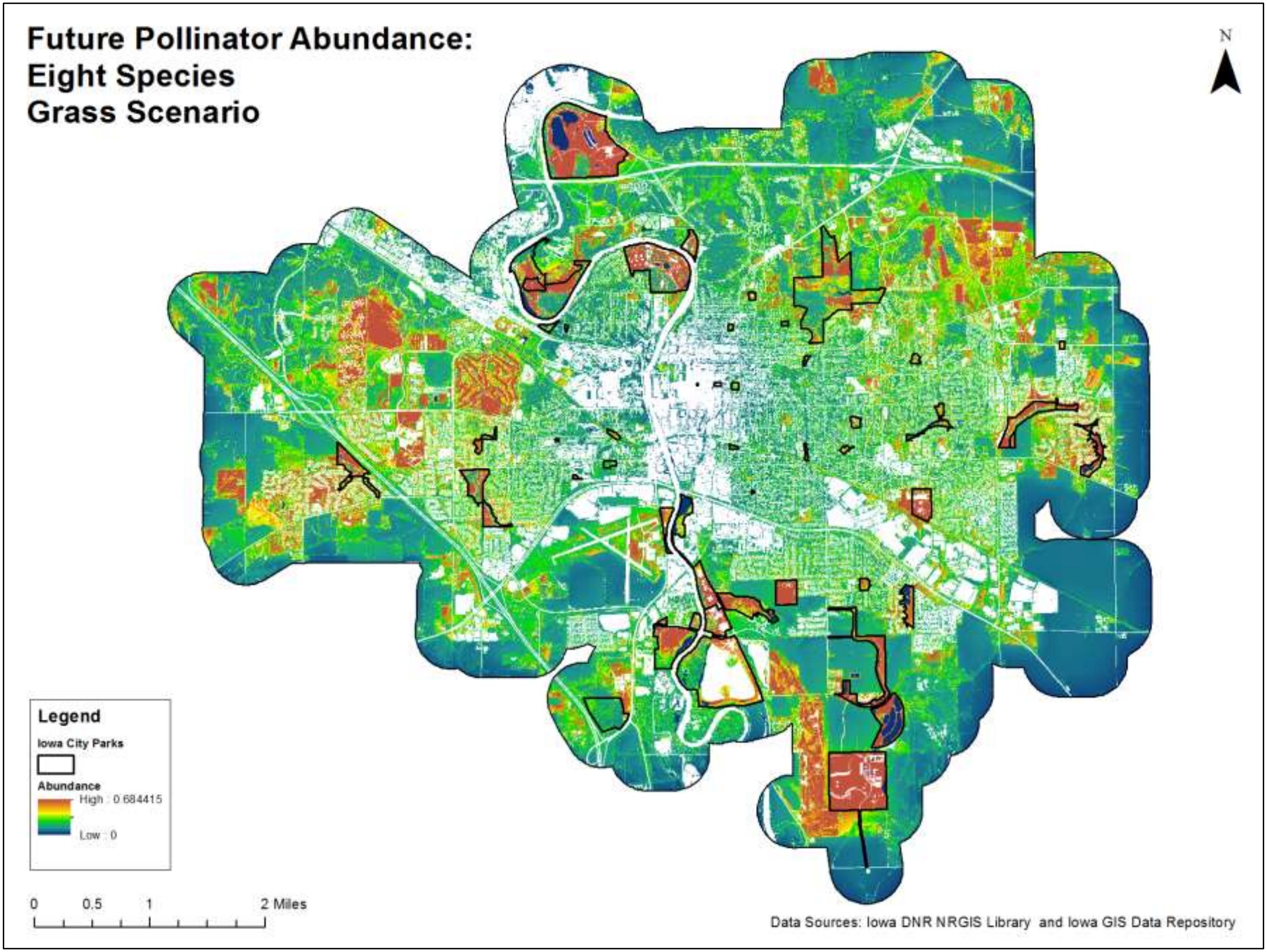

Figure 21 - Future pollinator abundance, tall grass/eight species scenario.

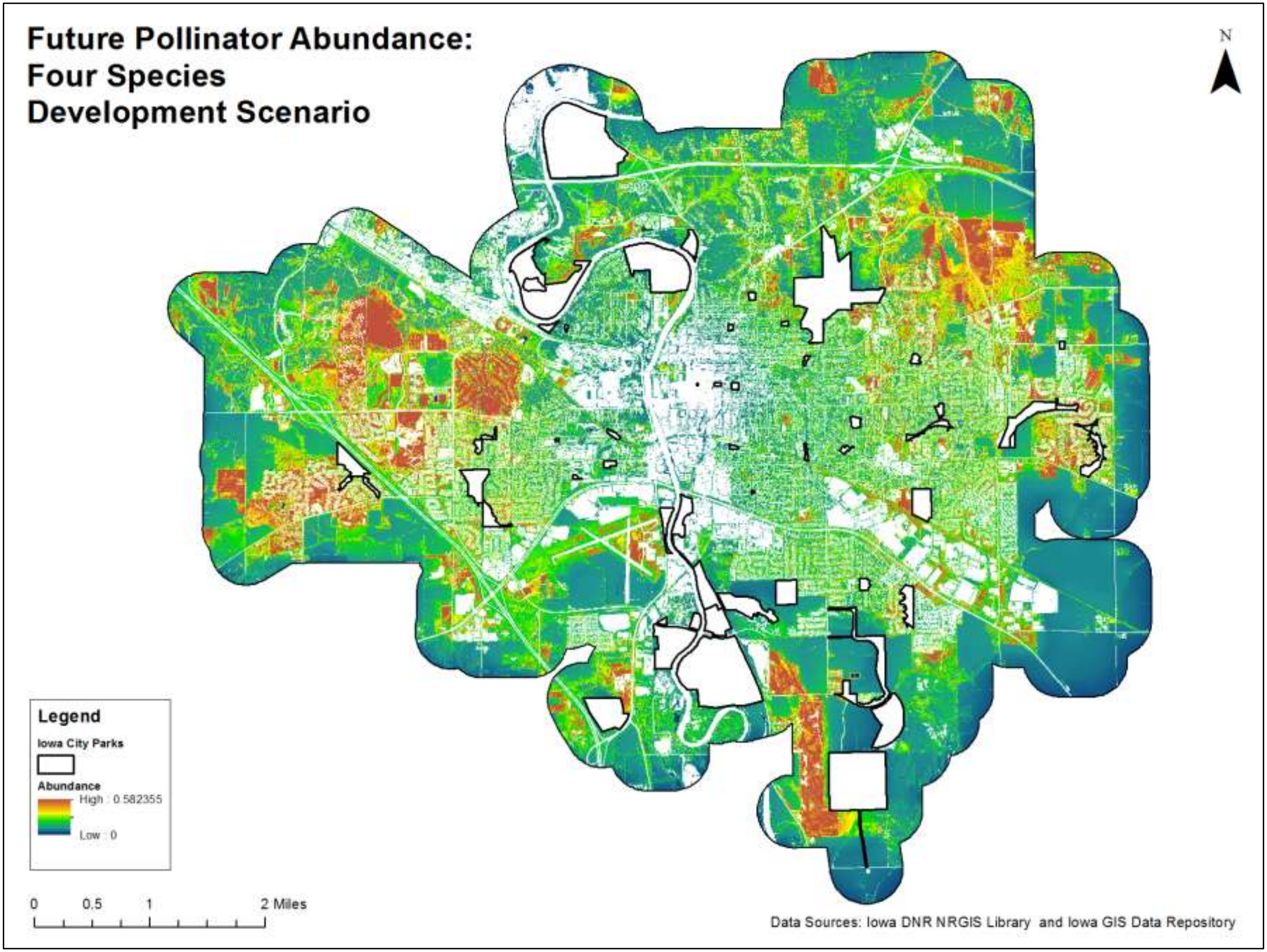

Figure 22 - Future pollinator abundance, development/four species scenario.

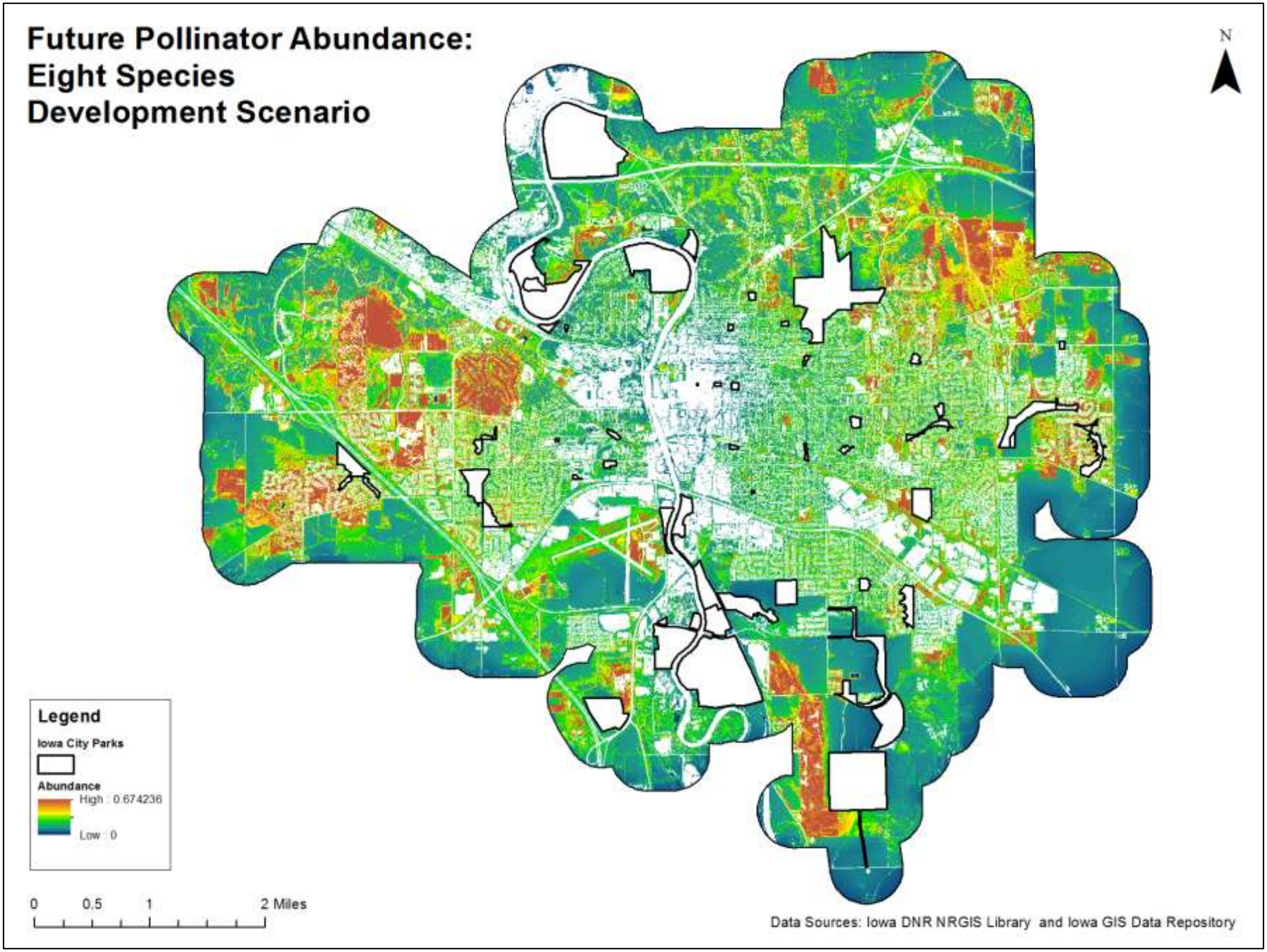

Figure 23 - Future pollinator abundance, tall grass/eight species scenario.

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