

Using Multispectral Analysis in GIS to Model the Potential for Urban Agriculture in Philadelphia

Abstract

In the context of growing concerns about the international food system's dependence on fossil fuels, soil degradation, climate change, and other diverse issues, a number of initiatives have arisen to develop and implement sustainable agricultural practices. Many of those seeking to reform the food system look to urban agriculture as a means to create localized, sustainable agricultural production, while simultaneously providing a locus for community building, encouraging better nutrition, and promoting the rebirth of depressed urban areas. The actual impact of such a system, however, is not well understood, and many critics of urban agriculture regard its implementation as impractical and unrealistic.

This project used multispectral, high-resolution images to quantify Philadelphia's capacity for urban agriculture to help city planners, entrepreneurs, community leaders, and citizens understand how urban agriculture can contribute to creating a sustainable food system in a major North American city. Multispectral images were classified with a maximum likelihood algorithm in ArcGIS to generate baseline data on vegetative cover in Philadelphia. These data, in addition to mapping on the ground, became the were used to model land suitable for conversion to agriculture in Philadelphia. The results of modeling found that there is enough available land in Philadelphia to create an urban agriculture system that would make and appreciable contribution to the city's food supply, but that its implementation would have to overcome a number of major hurdles including addressing soil contamination and investment costs.

Methods

The project approached calculation of agricultural potential in Philadelphia by using vegetative cover as an indicator of agriculturally viable land, using data on vegetative cover, in addition to mapping on the ground, to provide the basis of a model of land suitable for conversion to agriculture. A number of studies have shown that classification of multispectral aerial images provides an accurate and effective way to map urban vegetation.¹⁻³ This project utilized color infrared imagery from United States Department of Agriculture's National Agricultural Imagery Program with a one-meter resolution taken in August of 2004. Classification was performed with a maximum likelihood algorithm using ERDAS's Image Analysis extension for ArcGIS, and based on signatures taken from known cover types.

The initial classification had four classes: vegetation, low albedo, high albedo, and shadow. These classes are similar to those discussed by Song and Small, and allow the user to focus on vegetative cover and avoid some of the statistical noise that stems from the heterogeneous nature of high-resolution imagery of urban areas.⁴⁻⁵ Song and Small, however, only utilize three parameters in their classification schemes, vegetation, low albedo, and high albedo. For this project a fourth class, shadow, was added so that that shadowed vegetated land could be accounted for by finding the total area of shadowed land and assuming that the ratio of vegetated land to the other land cover types is roughly the same for all land types. The ratio of shadowed land to total land was used as a conversion factor for adjusting vegetated land estimates for the presence of shadow. The accuracy of the projections was determined by visual inspection of the images, ground-truthing, and repeated classifications were run to maximize accuracy. Figures 1-7 illustrate this process.

Further classifications and other editing was performed in order to provide a more informative description of land cover in Philadelphia. The initial classification lumped trees and other forms of vegetation into a single land cover type, vegetation. However, considering its sustainability focus, it would not necessarily make sense for urban agriculture to remove trees. Unfortunately, the Image Analysis program had difficulty differentiating between trees and other forms of vegetation in the same classification. However, a more accurate classification of tree cover was attained by performing a second classification that had only two endmembers- trees cover and non-tree cover. The area of tree cover obtained in this classification (not pictured) was subtracted from total vegetative cover to provide a value for the portion of vegetative cover in Philadelphia that is not made up of trees. The results of these classifications are listed in Table 1.

Because there are many Philadelphians who do not meet recommended levels of fruit and vegetable intake, the benchmark to compare potential yield is not current produce consumption, but rather "ideal" levels of consumption based on health data from the World Health Organization (WHO). The WHO recommends 400g of produce per person per day,⁶ which suggests that the city would require 226,300 metric tonnes of produce per year to meet the produce needs of its entire population of 1.55 million.

Estimates related to productivity were based on existing data on production in urban gardens in Philadelphia and data from a study conducted by the National Garden Association on home garden production. The Philadelphia data suggests yields of roughly 6,800 metric tonnes per km² (1.5 lbs per ft²).⁷ These data, however, vary significantly from national averages for home vegetable production of 2,500 metric tonnes per km² (0.5 lbs per ft²) found by studies conducted by the National Garden Association.⁷ Yield estimates have been generated based on both of these data. The respective production output values are listed in Table 2. PL1 refers to production level based on National Garden Association data, while PL2 refers to the production level based on current community garden output in Philadelphia.

Table 3 describes projected costs and benefits and labor requirements of expanding urban agriculture. Investment costs were estimated based on commonly used statistics of \$20 per ft² (about \$215 million per km²) to construct a community garden.⁹ Yearly costs were based on data from the National Garden Association that indicate that the average American gardener invests \$0.12 per ft² (\$1.25 million per km²). Value of production was derived from yield and assumes an average of value of \$2 per pound (\$4.4 per kg) of produce generated, a value used by both the study of Philadelphia gardening and the National Garden Association.⁷⁻⁸ Net value of production is simply the value of production minus yearly costs, while years to return on investment is the net annual value of production over the investment cost. Table 3 also describes the work force required to farm the given areas of land under two scenarios. The first scenario reflects current community garden structure in Philadelphia, based on estimates of 2000 workers for the 33 acre area currently under cultivation. This translates into an average land area of 69.7 m². These gardens, however, are largely recreational, and an alternative model for urban agriculture would be one based on professional growers. Historical data and data on urban agriculture in other countries suggest that a reasonable plot size for a single full-time worker would be 1 hectare (0.01 km²), this value is used in the second workforce scenario in table 3.

References

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Color Infrared Image Of Consolidated City-County of Philadelphia

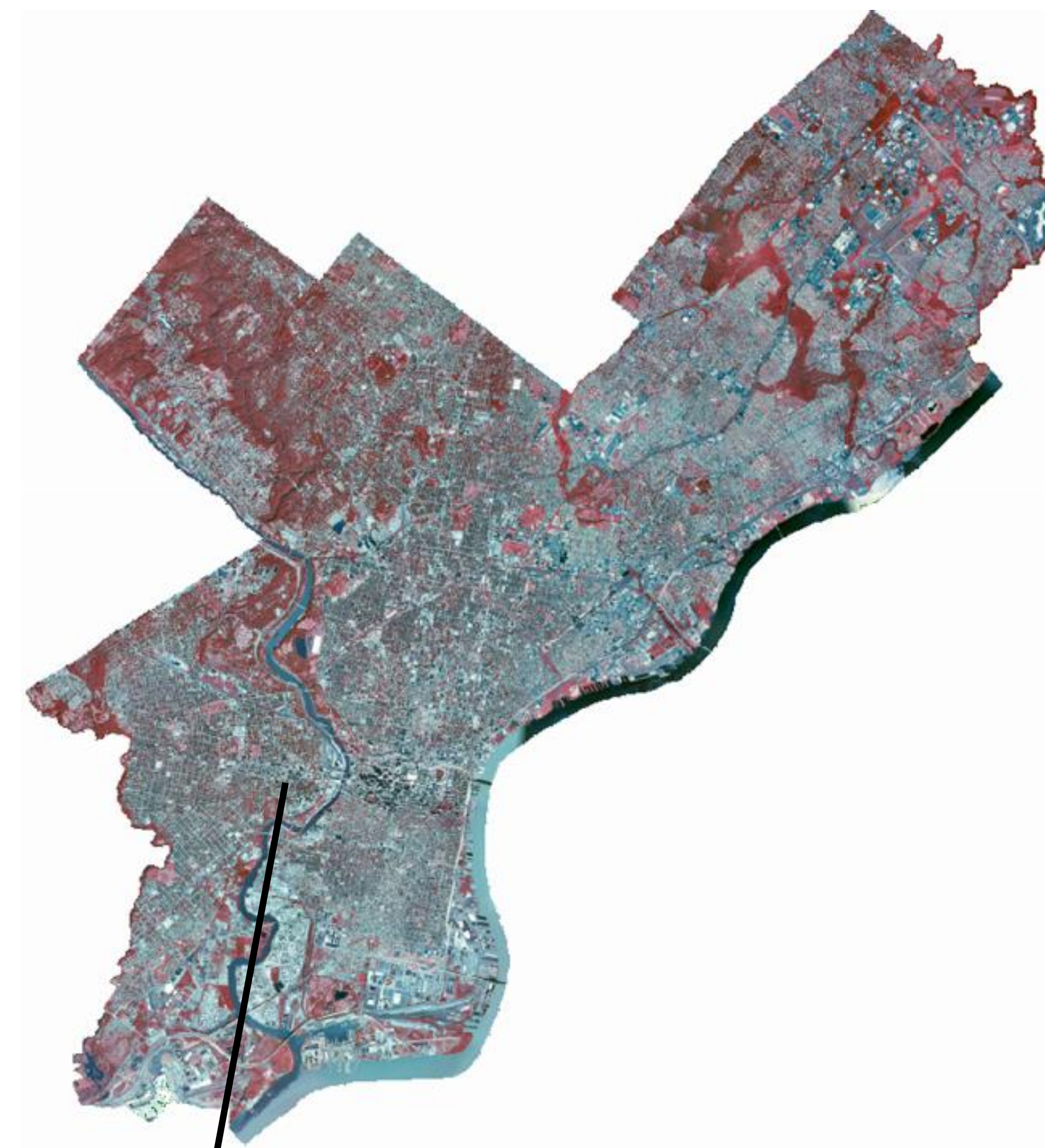


Fig. 1 Full extent unclassified



Fig. 3 Unclassified detail



Fig. 5 Ground truthing

Classified Image Of Consolidated City-County of Philadelphia

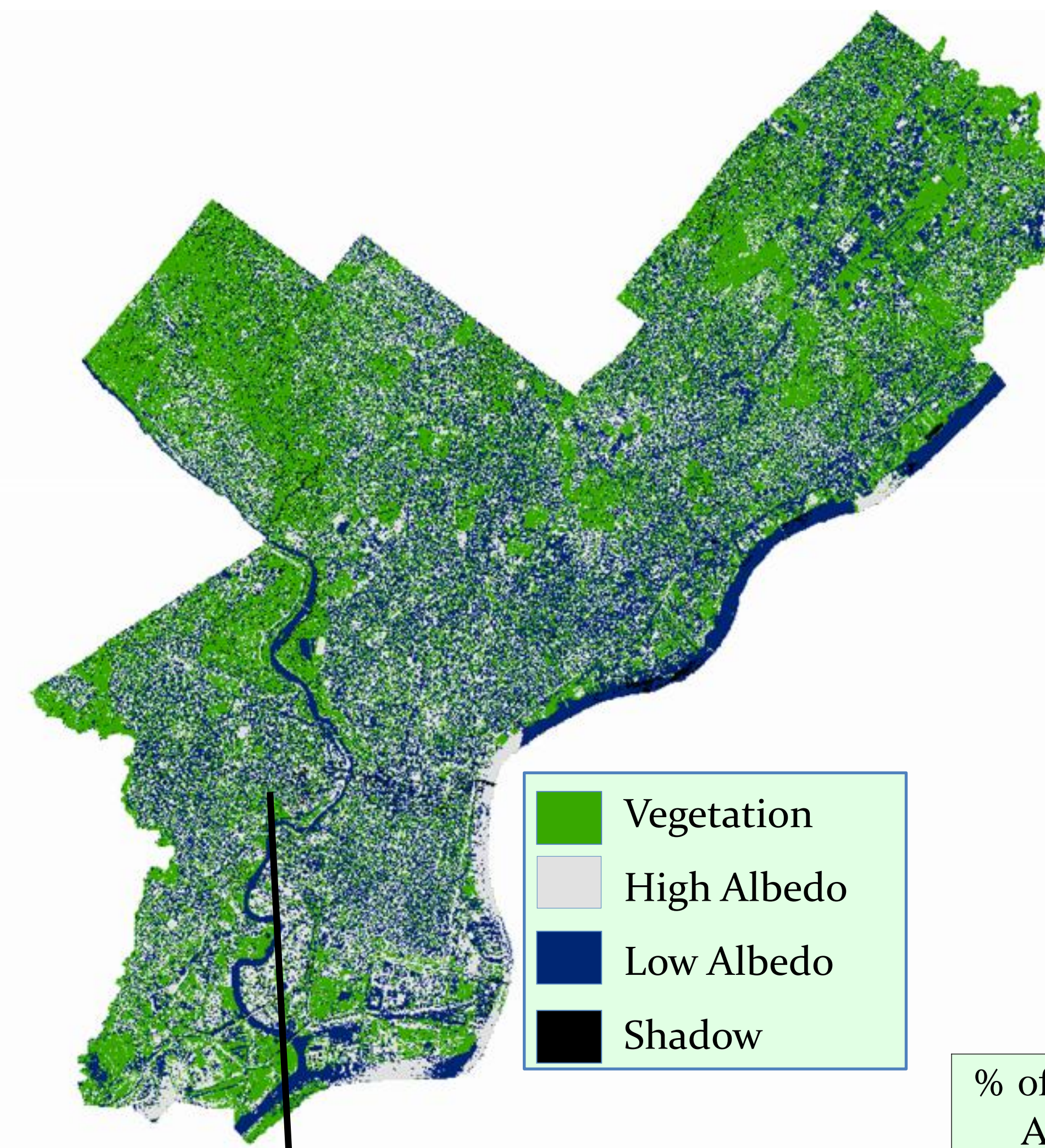


Fig. 2 Full extent classified

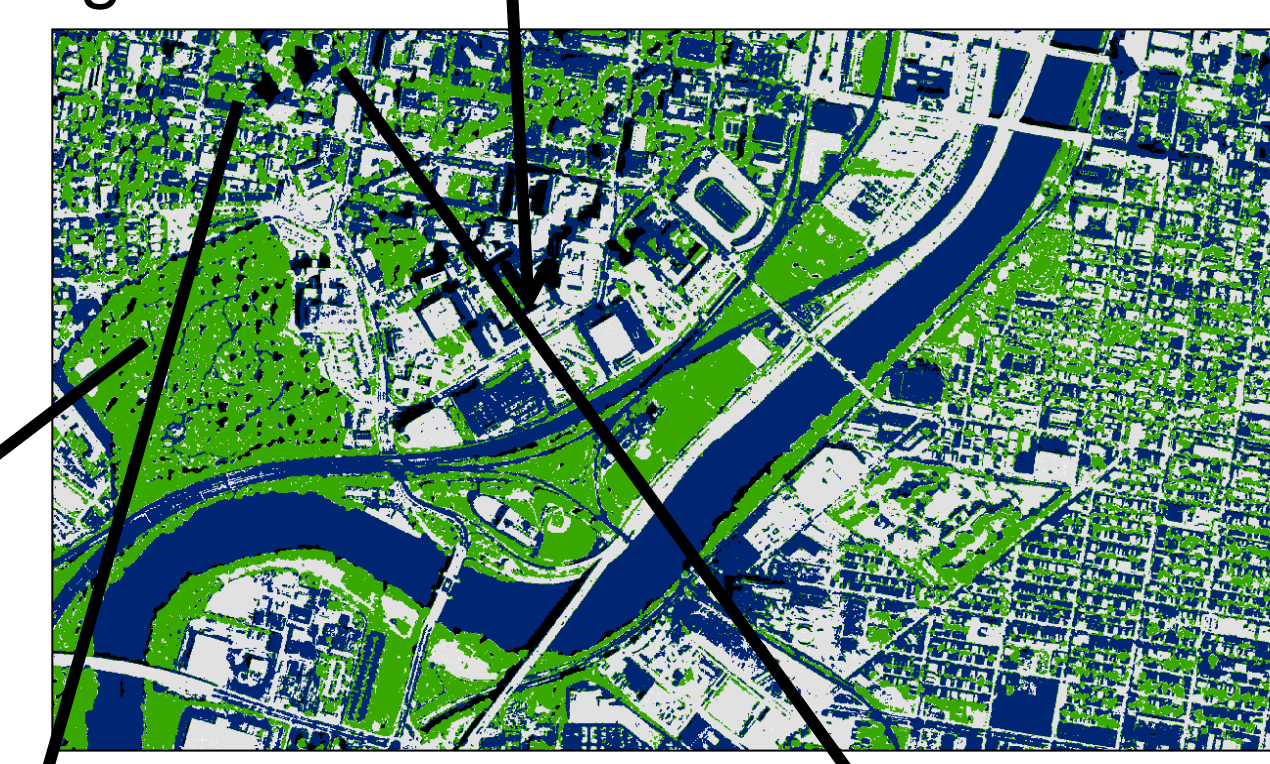


Fig. 4 Classified detail



Fig. 7 Ground truthing



Fig. 6 Ground truthing

Table 1. Classification results

	Area km ²	Shadow Adjusted Area km ²
Total Area	369	369
Vegetation	153.3	156.9
Trees	64.8	66.3
Non-tree Veg.	88.5	90.6
High Albedo	91.7	93.8
Low Albedo	115.5	118.2
Shadow	8.5	0

Table 2. Available land area and potential production statistics

% of Land Area	Area km ²	PL1 kg	PL2 kg	% of Goal PL1	% of Goal PL2
Current Production					
	0.133	324973	909925	0.1%	0.4%
Total Vegetated Area					
5%	7.8	19169547	53674733	8.4%	23.7%
10%	15.7	38339095	107349465	16.9%	47.4%
15%	23.5	57508642	161024198	25.4%	71.1%
20%	31.4	76678189	214698930	33.9%	94.8%
25%	39.2	95847737	268373663	42.3%	118.5%
30%	47.1	115017284	322048395	50.8%	142.3%
Non-Tree Vegetated Area Only					
5%	3.3	8098674	22676288	3.5%	10.0%
10%	6.6	16197349	45352577	7.15%	20.0%
15%	9.9	24296023	68028865	10.7%	30.0%
20%	13.3	32394698	90705153	14.3%	40.1%
25%	16.6	40493372	113381441	17.9%	50.1%
30%	19.9	48592046	136057729	21.4%	60.1%

PL1= Production Level 1—2,500 metric tonnes per km² (0.5 lbs per ft²)
 PL2= Production Level 2—6,800 metric tonnes per km² (1.5 lbs per ft²)
 Goal= 400g per person per day—226,300 metric tonnes for the whole city

Table 3—Financial Costs, Value of Production, and Labor

% of Land Area	Area km ²	Cost of Imp. (\$)	Yearly Costs (\$)	PL1 Val. of Prod. (\$/yr)	PL2 Val. of Prod. (\$/yr)	Work force-69.7 m ² plots	Work force-1 ha plots
Current Production							
	0.1	28632001	167020	1429882	4003670	1983	13
Total Vegetated Area							
5%	7.8	1688946903	9852190	84346008	236168823	116978	785
10%	15.7	3377893805	19704381	168692017	472337647	233956	1569
15%	23.5	5066840708	29556571	253038025	708506470	350934	2354
20%	31.4	6755787611	39408761	337384033	944675293	467913	3138
35%	39.2	8444734513	49260951	421730042	1180844116	584891	3923
30%	47.1	10133681416	59113142	506076050	1417012940	701869	4707
Non-tree vegetated area only							
5%	3.3	713539594	4162314	35634167	99775668	49420	332
10%	6.6	1427079188	8324629	71268335	199551337	98841	663
15%	9.9	2140618782	12486943	106902502	299327005	148261	994
20%	13.3	2854158376	16649257	142536669	399102674	197682	1326
35%	16.6	3567697970	20811571	178170837	498878342	247102	1657
30%	19.9	4281237563	24973886	213805004	598654011	296523	1989

Cost of implementation \$215 million per km²
 Annual Costs: \$1.25 million per km²
 Value of production: \$4.4 per kg
 PL1= Production Level 1—2,500 metric tonnes per km² (0.5 lbs per ft²)
 PL2= Production Level 2—6,800 metric tonnes per km² (1.5 lbs per ft²)

Conclusions and Further Study

The high resolution color infrared images used in this project are accurate enough to provide informative data on vegetative cover in Philadelphia, and suggest that there is a sufficient amount of potential agricultural land in the city to meet a significant proportion of the city's produce needs. This land could come from a variety of sources, such as private residences, vacant lots, and public park land. What is not clear, however, is whether meeting all of Philadelphia's produce needs is a reasonable goal, as that goal would require converting over 20% of the city's vegetated land to urban garden.

The major hurdle for urban agriculture is overcoming the high cost of investment. Even the scenario in which 3.3 km² are converted to urban agriculture, meeting between 3.5% and 10.0% of the cities produce needs, would cost \$713 million, 18% of Philadelphia's \$3.97 billion budget. Given the combination of social and economic benefits of urban agriculture, there is potential to gain both public and philanthropic support for urban agriculture initiatives. Many of the higher impact schemes would go well outside of the city budget. However, the prevalence of urban agriculture in the developing world suggests that these costs can be brought down significantly. If it is simply a matter of a farmer going out and digging beds, one would expect initial costs to be much closer to investment costs. Another significant challenge is addressing the issue of soil contamination. Although it is not clear exactly what the risks are, public policy trends rightly focus on ensuring that initiatives do not damage the health of the people they are seeking to help.

This project shows that spectral analysis provides an effective approach to assessing the potential for urban agriculture. More resources in terms of higher quality images and more advanced classification schemes would only increase the viability of using spectral analysis for determining the potential for urban agriculture. For example, advanced classification techniques can describe the plant species and the health of the vegetation, all of which could be used to better inform planners on the productive capacity of urban land.^{1-5,10} New research also promises to generate new spectral analysis techniques relevant to urban agriculture. One such area of research involves using spectral analysis to test for heavy metal content in vegetation. Although this has only been tested in labs, and has not been used in conjunction with aerial imagery, it could prove invaluable data for determining areas that are contaminated with heavy metals and other toxins.¹⁰ This project shows that spectral analysis can be used to provide insight into a variety scientific and policy concerns, and suggests that increasing the availability of high quality spectral imagery and developing new analytical techniques can greatly increase scientific understanding of human and natural systems, and help leaders in both the private and public sectors make better, more informed decisions.

Methodology-Conceptual Flow

