PORTLAND PARKS & RECREATION

Healthy Parks, Healthy Portland

Tree Canopy Monitoring:

Protocol and Monitoring from 2000-2015

June 2017

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Cover Photo: Mature elms create significant canopy in Ladd's Addition.

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Summary

To monitor trends in Portland's urban forest canopy, Portland Parks & Recreation established a protocol for measuring canopy change using point interpretation of aerial photos. Canopy cover was measured in 2000, 2005, 2010, and 2015 citywide and in commercial, industrial, open space and residential zoning classes.

Citywide canopy cover was 27.3% in 2000, 28.0% in 2005, 29.9% in 2010, and 30.7% in 2015. Across zones, canopy was highest in the open space zone and ranged from 53.9% in 2000 to 55.3% in 2010, but fell slightly to 54.9% in 2015. Residential zone canopy cover ranged from 29.8% in 2000 to 34% in 2015. Canopy was lowest in commercial and industrial zones. Commercial zone canopy ranged from 9.1% in 2000 to 13.3% in 2015. Industrial zone canopy ranged from 6.4% in 2000 to 9.5% in 2015.

From 2000 to 2015, statistically significant (McNemar's test, $p < 0.05$) increases in canopy cover were found citywide and in commercial, industrial, and residential zones. Citywide canopy cover increased by 3.4%, commercial by 4.2%, industrial by 3.1%, and residential by 4.2%. An increase of 1.0% found in open space zones during this period was not significant. Citywide, increases over the 15-year period represent an addition of 3,112 acres of canopy. The upward trend is positive and encouraging for the urban forest.

The protocol adopted in this study is an important step in a long term commitment to tracking canopy trends within the city and the next measurement will be taken in 2020.

Introduction

Canopy cover is identified as an important measure of urban forest health by the City of Portland. Canopy cover is a measure of Portland Parks & Recreation bureau-wide performance and is also cited as an important indicator in the *Portland Urban Forest Management Plan* (2004), *Urban Forest Action Plan* (2007), the *Portland Plan* (2012), the *Climate Action Plan* (2015), and the *2035 Comprehensive Plan* (2016). Monitoring Portland's tree canopy is important in order to understand how canopy coverage may be changing, and understanding canopy trends will allow managers to make important decisions regarding management strategies.

Canopy cover has been measured in a variety of ways within the City of Portland. Past studies have varied in methodology and time frame, and citywide canopy estimates from 1972 to 2014 range from 25% – 31% (Metro 2008 and 2016, Nowak & Greenfield 2012, Poracsky & Lackner 2004, PP&R 2007). These studies have provided important estimates of canopy cover, but differences in methodology preclude direct comparison of results for the purpose of detecting change.

Accurately detecting change requires establishing and using a replicable protocol with a low error rate. Canopy change occurs slowly, and in order to detect a change, the same method must be used over a period of time long enough for change to be evident. A successful monitoring protocol will use the same type and resolution of imagery, minimize and measure error, set thresholds for determining whether or not change has occurred, define a statistical method for comparing results, and be repeated at a regular time interval. This is vital to ensure that change reported is due to actual change, and is not a result of measurements being taken using different methods. If weighing canopy measurements against targets, progress towards targets will be measured using the same protocol.

To monitor trends in Portland's urban forest canopy, PP&R established a protocol for measuring canopy change according to the guidelines above, using point interpretation of aerial photos across four zoning classes and citywide, over five-year time increments. This report documents the adopted protocol and reports results for the study period from 2000-2015.

Monitoring Protocol

CHOOSING A METHODOLOGY

The goal of this canopy monitoring protocol is to determine how canopy is distributed among land use classes and citywide, and to determine how canopy is changing over time. Available methods for quantifying canopy were evaluated for their ability to answer these questions, including classification of remotely sensed data, ground sampling, and point interpretation of aerial photos. The benefits and drawbacks of each method were carefully weighed using the guidelines below.

- Canopy change methodology requirements:
- Low error rate
- Use imagery and technology that will continue to be available in future years
- Cost effective
- Replicable
- Peer reviewed with a recognized protocol
- Ability to subject results to quality assurance testing
- Ability to determine canopy cover for pre-defined strata and citywide
- Produce results that can be statistically compared for significance

Point interpretation of aerial imagery was selected, as it best met the above requirements. The primary drawback of point interpretation is the inability to produce cover maps. Point interpretation also cannot analyze canopy by categories not established at the beginning of the study (for example, neighborhood boundaries), as each strata requires a large number of sample points. However, the key goal of this project was to monitor canopy in predetermined strata and citywide, and cover maps and additional analysis are not required for this effort.

DEFINING STRATA

Recognizing that the city has different land use areas with varying characteristics and goals, strata were determined according to zoning classifications. Zoning classes are good proxies for the city's different land use types and best represent development intensity. Zoning classes also have some connection to the Urban Land Environments outlined in the 2004 *Urban Forest Management Plan*. Four strata were established corresponding to zoning code: commercial, industrial, open space, and residential (Table 1). All areas within the city's boundary were assigned to one of the zoning classes.

Table 1: Zoning Class Descriptions				
Zoning Class	**Zoning Code**	**Zoning Class Description**	**Acres**	**% of City**
Commercial	CO1, CN1, CO2, CN2, CG, CS, CM, CX	Storefronts, neighborhood and office commercial areas, and mixed residential commercial areas	6,237	6.7%
Industrial	EG1, EG2, IG2, IG1, IH, EX	Manufacturing and warehousing areas, industrial and wholesales sales, and industrial parks	21,507	23.2%
Open Space	OS	Natural areas, developed parks, and schools	16,819	18.1%
Residential	RF, R20, R10, R7, R5, R3, R2.5, R2, R1, RH, RX, IR	Single and multifamily residential homes	48,149	51.9%
			92,712	100.0%

APPLYING THE MONITORING PROTOCOL

PP&R contracted with Davey Resource Group, an experienced urban forestry consultant agency, to assist in establishing a protocol in 2012. The complete monitoring protocol is described in Appendix A.

Point interpretation was conducted by first establishing randomly located points across each zoning class. To keep standard error low, a minimum of 1,000 points were used for each zoning class for a total of 4,521 points. High resolution imagery was available back to 2000, thus years 2000, 2005, and 2010 became the first study years, and Davey Resource Group conducted point interpretation for these years. Subsequent point interpretation was conducted by Urban Forestry staff for year 2015.

For each study year, points were laid in the same geographic location on aerial images and a trained photo interpreter examined the points to determine whether the points coincided with tree canopy or not. To ensure that the photo interpretation process was completed with the highest degree of accuracy, a second photo interpreter performed quality assurance inspections on 10% of the work performed to verify the interpretations, with a 95% agreement threshold.

A percent canopy cover was determined for each zoning class, and the number of acres of canopy was calculated by multiplying the percentage of canopy by the total acres within the zoning class. Citywide canopy levels and acreages were calculated as weighted averages of the zoning classes. Standard error and 95% confidence intervals were calculated, and change over time was tested for significant difference using a Chi-squared test (McNemar's test) and significant differences were found if $p < 0.05$.

Findings

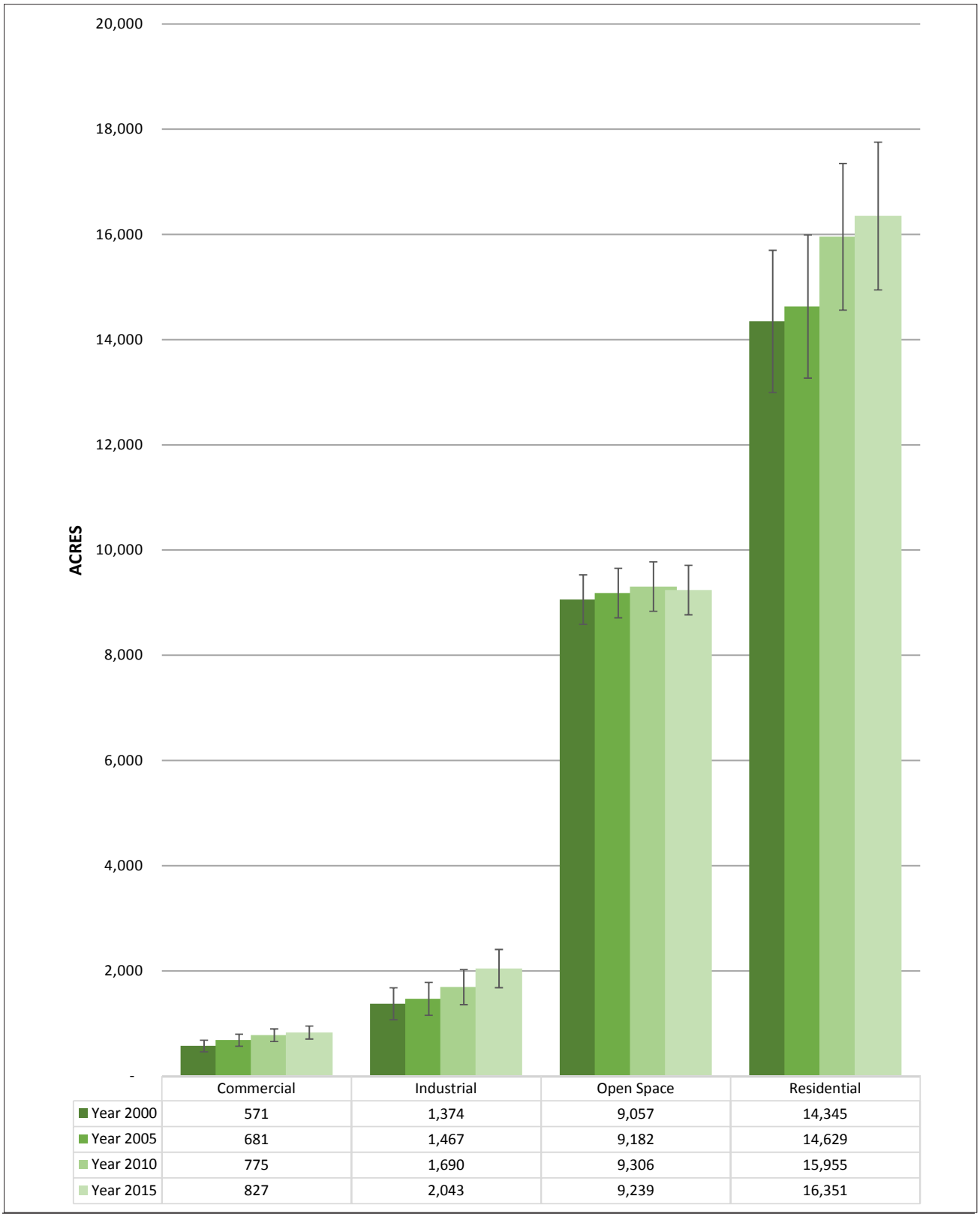
CANOPY COVER AND ACRES OF CANOPY

Total canopy acres found in the city ranged from 25,348 in 2000 to 28,459 in 2015 (Table 2). Overall canopy cover ranged from 27.3% in 2000 to 30.7% in 2015. Canopy cover was found to be unevenly distributed among the four zoning classes (Figure 1).

Table 2: Percent canopy and acres of canopy in 2000, 2005, 2010, and 2015. Findings reported with 95% confidence intervals.

	2000		2005		2010		2015	
Zoning Class	**Percent Canopy**	**Acres of Canopy**	**Percent Canopy**	**Acres of Canopy**	**Percent Canopy**	**Acres of Canopy**	**Percent Canopy**	**Acres of Canopy**
Commercial	9.1 ± 1.7	571 ± 105	11.0 ± 1.8	687 ± 114	12.5 ± 1.9	781 ± 121	13.3 ± 2.0	827 ± 124
Industrial	6.4 ± 1.4	1,374 ± 303	6.8 ± 1.5	1,467 ± 312	7.9 ± 1.5	1,690 ± 333	9.5 ± 1.7	2,043 ± 363
Open Space	53.9 ± 2.8	9,057 ± 471	54.6 ± 2.8	9,182 ± 470	55.3 ± 2.8	9,306 ± 469	54.9 ± 2.8	9,239 ± 470
Residential	29.8 ± 2.8	14,345 ± 1,353	30.4 ± 2.8	14,629 ± 1,361	33.1 ± 2.9	15,955 ± 1,393	34.0 ± 2.9	16,350 ± 1,404
City Total	**27.3 ± 2.4**	**25,348 ± 2,232**	**28.0 ± 2.4**	**25,965 ± 2,257**	**29.9 ± 2.5**	**27,732 ± 2,316**	**30.7 ± 2.5**	**28,459 ± 2,361**

Figure 1: Acres of canopy in zone classes in 2000, 2005, 2010, and 2015. Error bars represent 95% confidence intervals.



	Commercial	Industrial	Open Space	Residential
Year 2000	571	1,374	9,057	14,345
Year 2005	681	1,467	9,182	14,629
Year 2010	775	1,690	9,306	15,955
Year 2015	827	2,043	9,239	16,351

In commercial zones, between 571 acres (2000) and 827 acres (2015) of canopy were found, with total canopy cover ranging from 9.1% in 2000 to 13.3% in 2015. Commercially zoned lands contain approximately 3% of the city's total canopy acres.

In industrial zones, between 1,374 acres (2000) and 2,043 acres (2015) of canopy were found, with total canopy cover ranging from 6.4% in 2000 to 9.5% in 2015—the lowest of any zoning class. Industrial zoned lands contain approximately 7% of the city's total canopy acres.

In open space zoned lands, between 9,057 acres (2000) and 9,306 acres (2010) of canopy were found. Open space zones have the highest rate of canopy cover found in any zoning class, with findings ranging from 53.9% in 2000 to 55.3% in 2010. In 2015, decreases in total canopy acres (9,239) and canopy cover (54.9%) were found. Open space zoned lands contain approximately 33% of the city's canopy.

In residential zones, which make up the largest portion of the city's land base, between 14,345 acres (2000) and 16,350 acres (2015) of canopy were found, with total canopy cover ranging from 29.8% in 2000 to 34.0% in 2015. Residential zones contain the majority of the city's canopy and the most of any zoning class at approximately 58% of the city's total.

CHANGE OVER TIME

From 2000 to 2005, increases in canopy cover were found citywide and in all zoning classes (Table 3), however only changes in commercial zones were statistically significant (McNemar's test, $p < 0.05$), where canopy rose from 9.1% to 11.0% during the time period.

From 2005 to 2010, significant increases in canopy cover were found citywide and in all zoning classes with the exception of open space. Citywide canopy cover increased by 1.9%, commercial by 1.5%, industrial by 1.0%, and residential by 2.8%.

Table 3: Change in canopy cover from 2000 to 2015

	2000-2005		2005-2010		2010-2015	
Zoning Class	**Percent Change**	**Change in Acres**	**Percent Change**	**Change in Acres**	**Percent Change**	**Change in Acres**
Commercial	+1.9*	+116*	+1.5*	+94*	+0.7	+46
Industrial	+0.4	+93	+1.0*	+223*	+1.6*	+353
Open Space	+0.7	+124	+0.7	+124	-0.4	-66
Residential	+0.6	+284	+2.8*	+1,326*	+0.8	+395
City Total	**+0.7**	**+617**	**+1.9***	**+1,767***	**+0.8**	**+728**

* Change significantly different with $p < 0.05$ (McNemar's test)

In the latest period, from 2010 to 2015, increases in canopy were found in all zoning classes except open space, however the only significant change was seen in industrial zones, which increased by 1.6%, from 7.9% to 9.5% canopy cover.

Over the fifteen year period, from 2000 to 2015, canopy cover increased significantly citywide and in all zoning classes, with the exception of open space (Table 4). Citywide canopy cover increased by 3.4%, commercial by 4.2%, industrial by 3.1%, and residential by 4.2%. Citywide, increases represent an estimated addition of 3,112 acres of canopy.

Table 4: Change in canopy cover from 2000 to 2015

Zoning Class	Percent Change	Change in Acres
Commercial	+4.2*	+256*
Industrial	+3.1*	+669*
Open Space	+1.0	+182
Residential	+4.2*	+2,005*
City Total	**+2.6***	**+3,112***

* Change significantly different with $p < 0.05$ (McNemar's test)

Discussion

CANOPY DISTRIBUTION AND TRENDS

From 2000-2015, canopy cover significantly increased citywide and across commercial, industrial, and residential zones. For each five-year time period, canopy increases were found citywide and across all zones, with the exception of a decrease found in open space from 2010-2015, but not all changes were statistically significant.

Although fifteen years is a relatively short period of time, the upward trend is positive and encouraging for the urban forest. The most recent five year interval, 2010-2015, suggests a slowing in this trend, however additional time and monitoring will reveal more information on longer term canopy trends within the city.

Canopy cover varied greatly between zoning classes, and the uneven distribution reflects land use and intensity of development. For example, the open space zone has the highest rate of canopy cover, and increases found over the study period were statistically insignificant. Open space areas include natural areas and developed parks, many of which likely maintain stable canopy levels for their particular land uses. In contrast, residential, commercial, and industrial zones are more likely to undergo development changes and are likely to have more opportunities for planting and growing trees. These zoning classes are likely to experience the most change in canopy cover.

COMPARISON TO CANOPY COVER TARGETS

PP&R's 2004 *Urban Forest Management Plan* (UFMP) set aspirational canopy cover targets for Urban Land Environments (ULEs) (Table 5).

Targets were established by reviewing recommendations for canopy cover in scientific literature. ULEs were derived from Metro's Regional Land Information System, and have some connection to the zoning code categories used in this study. Note that ULEs are now outdated and may include up to 20% classification error (PP&R 2009). The two ULEs that correspond best with zoning categories are the residential ULE and the commercial/ industrial/ institutional ULE. The *Urban Forest Management Plan* recommends targets of 35-40% canopy cover for the residential ULE and 15% for the commercial/industrial/institutional ULE. In 2015, canopy levels have not yet met these goals: in the residential zone canopy cover was 34.0%, the commercial zone was 13.3%, and the industrial zone was 9.5%.

PP&R's *Canopy Report* (2007) and City of Portland's *Climate Action Plan* (2009 and 2015) set a goal of expanding urban forest canopy to cover one-third of the city's area. The 33.3% citywide goal was established

Table 5: Existing canopy cover targets within the City of Portland		
Category	**Canopy cover targets in UFMP (2004)**	**Canopy goals in PP&R Canopy Report (2007) and Climate Action Plan (2015)**
Residential ULE	35-40%	n/a
Commercial/Industrial/Institutional ULE	15%	n/a
Natural Areas and Stream Corridors ULE	Targets set by City Framework Plan	n/a
Transportation Corridors and Rights of Way ULE	35%	n/a
Developed Parks and Open Spaces ULE	30%	n/a
Citywide	No target set	33.3%

from canopy cover data produced using a different method than that used in this report, and direct comparison of results is not recommended.

This monitoring protocol and report of results provides baseline data that can be used to establish and refine canopy targets. The *Urban Forest Management Plan* is scheduled to be updated in the next two years, and would provide an excellent opportunity for revising canopy goals. An evaluation of potential tree canopy would aid in establishing realistic targets (PP&R 2015). Well developed canopy targets will provide the opportunity to make deliberate and clear decisions for planning and goal setting for the future of the urban forest.

In addition to a citywide canopy target, canopy targets by zone classes are recommended due to the fundamental differences in zones in land use characteristics, existing canopy, and capacity to accommodate tree canopy in the future. Zone class targets will assist managers in developing effective strategies for increasing canopy, and may also assist the City in reaching its other tree goals, such as more equitable distribution of trees.

OPPORTUNITIES FOR FUTURE STUDY

Establishing and applying a monitoring protocol has been an important step in a long term commitment to tracking canopy trends. The protocol outlined in this study will continue to serve as guide for PP&R in future years and the next canopy measurement will occur using 2020 aerial images.

This monitoring study reports trends in canopy, but does not provide information on why changes are occurring. Canopy increases may be attributed to growth of existing trees and planting of new trees. Tree removal for development, tree loss from pests and diseases, natural mortality, and weather events may negatively affect canopy cover. Examination of the reasons behind canopy trends requires additional study and would allow for more informed strategies for meeting canopy goals.

Additionally, this study does not provide information on canopy cover levels or change in areal units other than zoning classes or citywide. Other boundaries of interest may be useful, such as at the neighborhood level or across private versus public property. An image classification study recently

completed by a local consortium of agencies (Metro 2016) provides this opportunity; while not strictly comparable to data presented in this report, this map of Portland's canopy is complementary and will aid understanding of the composition and distribution of trees in Portland.

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Appendix A: Canopy Monitoring Protocol

Method: Point interpretation of aerial photos

Measurement frequency: 5 years

Image standards: Color digital orthorectified photos at 6" resolution taken during leaf on season

Strata: Commercial, industrial, open space, and residential according to zoning code

Points: A minimum of 1,000 randomly selected points are established within each zoning class. The high sample number is needed to minimize standard error. A standard error threshold of 2% is established. If standard error for any zone exceeds 2%, additional sample points should be established until the standard error threshold is reached. Future analyses use the same established points.

Interpreting points: Points are interpreted as tree, non-tree, or unreadable. Unreadable points are removed from the sample.

Photo interpretation guidelines:

- Photo interpreters should have extensive experience interpreting aerial photography and relating photos to locations on the ground. Interpreters should have a high degree of confidence that they can differentiate between trees, lawn, buildings, roads, and other ground surfaces. This is a strategy to reduce errors that would occur when the interpreter records a tree when there is no tree, or fails to see the tree as occupying the point.
- The same photo interpreter should be used throughout the study, except for quality assurance testing.
- A second photo interpreter performs quality assurance testing on 10% of the data points. A 95% agreement must be reached for the data interpretation to be considered valid.
- Dead trees are considered "not tree." Because photos are analyzed in leaf-on season, trees devoid of leaves are considered dead or "not tree."
- Non-tree vegetation (e.g., hedges, low shrubs, green roofs, lawn) is considered "not tree."
- Points falling on water are included and are recorded as "not tree."
- In cases where the point falls on the edge of a tree, the interpreter will need to zoom in and carefully consider the image. Changes over time may be due to canopies growing into the location of the point, and it is important to spend the time to carefully analyze and capture these borderline changes.

- Images that are too difficult to interpret due to large dark shadows from buildings or very large trees are considered "unreadable" and are excluded from the study.
- Due to the nature of aerial photography, minor displacement occurs due to horizontal and parallax variation from year to year. To minimize bias, these changes are ignored and each photo is assumed to be correct. Although this may introduced error in some borderline cases, it is assumed that error is equally randomly distributed between tree and non-tree points.

DATA ANALYSIS

Zoning class canopy cover percentage (p): The number of sample points (N) interpreted as "tree" divided by the total number of sample points (n) within the zone (p=N/n).

Zoning class canopy acres: The percentage of canopy cover (p) multiplied by the total acres of land within that zone.

Citywide canopy acreage: The sum of canopy acreages in each zone.

Citywide canopy cover percentage: The total acres of canopy were divided by the total acres of land in the city to give a citywide canopy percentage.

Standard error (SE): $\sqrt{((p \times (1-p)/n)}$ (Lindren and McElrath 1969)

Confidence interval: A 95% confidence interval is set and is calculated as: SE x 1.96 (Thompson 2002).

Significance testing: For each zone and citywide, McNemar's test is used to determine whether changes observed in canopy coverage are statistically significant (Sokal and Rohlf, 2003). McNemar's test is a non-parametric method used on nominal data. The test provides a chi-squared value, which is compared against a p-value for statistical significance. Canopy cover between years and across zones is considered significantly different if $p < 0.05$. A weighted total is used to calculate citywide chi-squared using McNemar's test. Each number of sample points (N) was multiplied by the portion of the city covered by each zone to calculate the total.