WINDOWS AND VEGETATION: PRIMARY FACTORS IN MANHATTAN BIRD COLLISIONS

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ABSTRACT. --- Bird collisions in Manhattan (New York City) were studied by analyzing collision data collected from 1997 to 2005 by Project Safe Flight (PSF) participants, representing one of the largest collision monitoring efforts in the nation. Over 4,500 bird collisions were recorded during this period, two-thirds of which were fatal. Collisions involved 101 bird species, primarily from the warbler, sparrow, and thrush families, and mostly during spring and fall migration. Most collisions were documented to occur during the day at the lower levels of buildings where large glass exteriors reflected abundant vegetation, or where transparent windows exposed indoor vegetation. Most collisions in Manhattan likely occurred at a handful of high-collision sites where strike rates of well over 100 birds per year are considerably higher than previously reported rates. We suggest here that improving our understanding of the factors involved in collisions at such sites could greatly assist in reducing bird collisions.

Bird collisions with human-made structures have been documented extensively for over a century (Klem 1989). After habitat loss and fragmentation, collisions with such structures represent the greatest human-related threat to bird populations (Klem et al. 2004). Species involved in collisions are also listed on the US Fish and Wildlife Service's *Birds of Conservation Concern* and on the *Audubon WatchList* (Shire et al. 2000). Collisions with reflective and transparent plate glass are estimated at 100 to 1,000 million birds for the continental US (Klem 1990), posing a threat to resident and migratory birds (Klem 1989, 1990, Veltri and Klem 2005). This threat is likely to increase as more natural habitat is modified through development that incorporates such glass (Klem 1990). Night collisions with structures such as communications towers also pose a threat to nocturnal migrants, especially during inclement weather (Avery et al. 1976, Shire et al. 2000, Gauthreaux and Belser 2003, Veltri and Klem 2005).

In recent years, bird-rescue organizations in Chicago (Chicago Bird Collision Monitors), Toronto (FLAP – Fatal Light Awareness Program), and New York City (NYC Audubon's Project Safe Flight) have documented thousands of collisions at human-made structures, especially during spring and fall migration. However, to date, the majority of bird collision research consists of data gathered from rural and suburban environments. Additionally, while well-lit skyscrapers were first believed to be involved in most urban collisions (Ogden 1996), recent research suggests that nighttime collisions may be more limited in scope (DeCandido 2005). Other research and anecdotal information clearly documents extensive daytime collisions at low-rise buildings (Gelb and Delacretaz 2006, personal communication: Michael Mesure, Executive Director of FLAP).

Participants in Project Safe Flight (PSF) have been monitoring bird collisions in Manhattan (New York City) since 1997. This monitoring effort represents one of the largest in the nation, involving tens of program participants who dedicated what amounts to thousands of monitoring hours. By the end of 2005, participants in this program had recorded over 4,500 collisions, which were entered into an online database available on the NYC Audubon website. In this paper we use these data to answer important questions relating to frequency, timing (especially day vs. night), and physical context of collisions in Manhattan. Specifically, we sought to test two hypotheses: (a) that the frequency of collisions is highest along those portions of the exterior glass surface that reflect outside vegetation (reflective windows) or display indoor vegetation (transparent windows); and, consequently, (b) that most of these collisions occur during daytime hours when birds are feeding.

METHODS

Since 1997, a bird collision was recorded by program participants when a dead or injured bird was found at the base of a building, as indicated by other researchers (Klem 1989, 1990, Dunn 1993, O'Connell 2001, Klem et al. 2004). When monitoring the exterior of a building, participants walked the route slowly, looking for birds from the base of the building to the gutter on the near side of the street. Building exteriors (referred to here as "sites") were monitored once a day, usually in the morning hours during the spring (late March to early June) and fall (late August to early November) migration periods. Sites with high collision numbers (at least several collisions a day) were sometimes monitored more than once a day, while sites with low collision numbers (less than one a day) were sometimes monitored less than once a day. Daily monitoring was discontinued after collision numbers dropped substantially at the end of each migration season. Periodic monitoring during non-migratory seasons indicated that strike rates remained low during these periods. Program participants were trained to follow the same monitoring procedures.

We analyze Manhattan collision data collected from 1997-2005 to determine the top 20 species involved in collisions (Table 1) and to evaluate the role of daytime factors (vegetation and windows) and nighttime factors (building height and lighting) in causing bird collisions. We were unable to conduct a regression analysis here, as sites were not chosen randomly, and because monitoring effort and start dates differed across sites. Instead, we rank over 180 Manhattan sites to determine the top 10 sites with the highest collision numbers (Table 2). For these sties, as well as other sites described in this paper, we indicate total collisions recorded at the site, monitoring dates, and information relating to the factors involved in daytime and nighttime collisions. Window size and vegetation were categorized as follows: 1 – *large windows opposite some vegetation*; 2- *large windows opposite extensive vegetation, not adjacent towith no an urban park*; 3 – *large windows opposite extensive vegetation, adjacent to and an urban park*. For the purposes of this analysis, *large windows*, either reflective or transparent, were 1 m x 2 m, or larger, along the building exterior; *extensive vegetation* signifies that 50% or more of the windows at the lower levels either reflected exterior vegetation or displayed indoor vegetation *and* that this vegetation was composed of at least a row of trees with interlocking canopies or dense shrubs, 5-15 m from the windowed exterior (reflective windows), and a row of trees or dense shrubs, 0-15 m (transparent windows); *some vegetation* signifies that this value was less than 50% *and* that vegetation was less dense along the windows; the size of an *urban park* was one-half hectare or more, composed of trees and shrubs, opposite the building exterior. Building height was measured in meters. Artificial light emitted from building was categorized as follows: 1 – *little to no light emissions*; 2 – *emissions from internal light source only*; 3 – *emissions from internal light and external bright lights at the top of the building*. Light intensity was gauged during random nighttime visits to the sites in question and by looking at photographs of the sites at night. In this analysis, we include the "Twin Towers" of the now destroyed World Trade Center complex, noting that monitoring was discontinued in fall 2001. We remove two sites from the top 10 list due to uncertainty relating to the precise building areas that were monitored.

In addition to ongoing monitoring of sites across Manhattan, we conduct extensive monitoring during 2005 at two separate locations – a downtown location comprising of six buildings and the midtown location of the Morgan Processing and Distribution Center (Morgan Mail building) (Figure 1).

Downtown Study: The week-long "downtown study" (noon, May 7th, to noon, May 14th, 2005) tested the hypothesis that most collisions occur during the day by intensively monitoring six buildings (At center of the route: 40° 42'11" N, 74° 00'43" W), four of which were skyscrapers that emitted artificial light during nighttime hours (Figure 2). All but one building included reflective exteriors with some to little vegetation nearby. All exterior walls ran straight from the base of the buildings to the rooftops, with no setbacks or ledges that could prevent colliding birds from falling to the street level. Building exteriors were purposely chosen so that they faced the general direction of spring migration in order to maximize the potential number of collisions. Proximity to mass transit (i.e., subway stations) was also a factor in selecting study sites in order to ensure easy access for study participants. For comparison purposes, we monitored the Morgan Mail building and the World Financial Center complex, sites not immediately in the study location which were already documented to be high-collision sites (defined here as sites with over 100 collisions per year). See Table 3 for more information.

The downtown study was conducted during the period when spring collisions generally peak (Figure 3). In order to accurately document the time of collisions, 22 participants monitored the six building exteriors during the following time periods: 0:00-0:30, 4:00-4:30, 6:00-6:30, 8:00-8:30, 12:00-12:30, 16:00-16:30, and 20:00-20:30. The additional morning session of 8:00-8:30 was added in order to record collisions that would otherwise be hard to detect during the morning commute in this busy downtown area. The same route (590 m) was walked during each monitoring session, beginning at 1 Battery Park Plaza and ending at 55 Water Street. Participants recorded their findings on a data sheet that included the study route and a map on which to mark where birds were found. Morgan Mail and the World Financial Center, the two additional high-collision sites added for comparison purposes, were monitored only once each morning during this study. Skies were mostly clear during the week-long study. The first days saw periods of overcast skies, beginning after midnight on the first night and lasting into the afternoon of the second day, and then beginning before midnight on the second night and dissipating by early morning; no precipitation was recorded throughout the study period. As was our experience in prior years, collisions at sites across the City clearly peaked on May 12th. Given that only four collisions were recorded throughout this study, this study is treated here in a more qualitative and descriptive fashion.

Morgan Mail Studies: We conduct two separate studies at the Morgan Mail building (Figure 1), a six-story office building where relatively high numbers of collisions have been recorded since 2002. The building is located in Manhattan between 28th and 29th Streets and between 9th and 10th Avenues (40° 45’ 02” N, 74° 00’ 01” W). The building’s exterior was made up of windowless concrete walls for the first two stories and 440 large, reflective glass panels (each 2.3 m x 1.3 m) covering approximately 75% of the remaining four stories (the “windows” actually mask a concrete wall). All exterior walls ran straight from the base of the building to the rooftop, with no major outcrops or ledges that could prevent colliding birds from falling to the street level. The southern perimeter of this building (247 m) faced a row of short street trees that did not reach the building windows. Across the street was a row of large street trees (mostly London Plane trees, Platanus x acerifolia), many of which were over 20 m tall and reached to the top of the six-story structure. Beyond this row of trees extended a rectangular, 1.42-hectare urban park (Chelsea Park) with more tall trees (mostly London Plane trees), some of which were also reflected in the building windows. The vegetation at this park was not uniformly distributed; whereas the eastern portion of the park included many large trees, the western portion of the park – amounting to slightly less than half of the entire park – was much less vegetated, partly due to the fact that most of the space was taken up by a large ball-field covered with artificial turf.

The first study, carried out during spring and fall, tested the hypothesis that the frequency of collisions is highest along those portions of the exterior glass surface that reflect outside vegetation by recording the locations of collision victims along the building’s southern perimeter. As noted above, the eastern portion of the southern perimeter faced more vegetation than did the western portion. To estimate the quantity of vegetation in each of these sections, we divided the southern perimeter into approximately equal halves and counted the number of trees in each half that reached up to the fifth and sixth floors along the sidewalk opposite the building. There were 12 such trees along the eastern half (“vegetated” section) and four trees along the western half (“less-vegetated” section). The positions of dead and injured birds found at the base of the building were carefully noted and assigned to one or the other of these two sections. In some instances, especially during the spring, volunteers did not record the precise locations of dead and injured birds; data from these days were not included in the statistical comparison of collisions along the vegetated vs. less-vegetated sections.

The second study, referred to here as "the three-day study" (October 18th to October 20th, 2005), tested whether most collisions occur during the day in areas where the exterior glass surface reflects outside vegetation. In this study, eight participants monitored the building exterior during the following time periods: 6:45-7:15, 9:00-9:30, 12:00-12:30, 15:00-15:30, and 19:00-19:30. For the purposes of this study alone, the building's western perimeter, extending from 28th to 29th Street (58 m), was also monitored. This perimeter, which had no tall trees adjacent to it, served as a qualitative control for the presence of vegetation. Sunrise during this study was at approximately 7:10, with Civil Twilight at approximately 6:45; sunset was at approximately 18:10 EDT. Weather conditions during the study were generally favorable, with little to no cloud cover throughout the study period.

The collision data presented here is very likely an underestimate of the true number of collisions because of our inability to continually monitor all sites. Additionally, "removal bias," i.e., the removal of dead and injured birds by predators and scavengers (Dunn 1993, O'Connell 2001, Klem et al. 2004) or by street sweepers and building maintenance staff (Klem 1990, O'Connell 2001) further reduces the true number. To correct for these sources of bias, we substantially increased the monitoring frequency at the two sites mentioned above. While not eliminating these sources of bias, the increased monitoring effort represents a considerable improvement over monitoring that is performed only once a day. It is unlikely that the downtown area included many scavengers, given the scarcity of natural habitat at the site; bird samples that remained in tact for over a day at the base of the Morgan Mail building suggest that removal by predators was not a serious factor at this site as well. Sweepers were more prevalent in the downtown study, where they could have been a biasing factor. Finally, while adding more individual monitors represents a new source of bias, we believe that the relative ease with which one can identify a dead or injured bird ensures that the reduction in removal bias justifies this procedure.

We used binomial goodness-of-fit, two-tailed test to evaluate experimental results. We considered test results to be statistically significant when $P < 0.05$. We used SPSS 12.0.0 for Windows, release Sep. 2003.

RESULTS

Participants recorded over 4,500 bird collisions in Manhattan from 1997-2005, two-thirds of which were fatal. 101 bird species were involved in these collisions, most of which were passerines, primarily from the warbler, sparrow, and thrush families (Table 1). Most collisions involved passage-migrants during spring and fall migration (Figure 3).
Table 1:
Figure 3:

Collision numbers for Manhattan's top 10 collision sites ranged from 470 to 83. Of the 180 sites analyzed, several of which were tall structures, about two-thirds registered collision numbers ranging from 1 – 10 only. All ten sites on the Top 10 list included large windows, with the World Trade Center's Twin Towers, the World Financial Center's Winter Garden, and Chase Plaza including transparent windows. All sites incorporated vegetation, with the Twin Towers and Winter Garden including visible indoor vegetation; eight of the sites incorporated extensive vegetation, four of which were also opposite an urban park. Four of the sites were low-rise buildings (>40 m), three of which were mostly dark during the night.
Table 2:

Participants recorded only four collisions during the downtown study, two of which were fatal. Birds found during the three-day study were distributed among monitoring periods as follows: 0:00-0:30: 0 birds; 4:00-4:30: 1 bird; 6:00-6:30: 1 bird; 8:00-8:30: 2 birds; 12:00-12:30: 0 birds; 16:00-16:30: 0 birds; and 20:00-20:30: 0 birds. During the same period, we recorded 14 and 24 collisions at the Morgan Mail building and the World Financial Center, respectively.
Table 3:

Of the 251 collisions recorded during the spring and fall periods at Morgan Mail, we mapped the collision locations of 144. Strike frequency differed significantly between the vegetated (105) and less-vegetated (39) halves of the southern perimeter (Binomial test, $Z = -5.42$, 2-tailed, $P < 0.0001$).

During the three-day study at Morgan Mail, participants recorded 28 collisions involving 13 different bird species, 23 of which were fatal (82%). Dead and injured birds found during this study were distributed among monitoring periods as follows: 6:45-7:15: 6 birds; 9:00-9:30: 13 birds; 12:00-12:30: 7 birds; 15:00-15:30: 2 birds; and 19:00-19:30: 0 birds. Of the total number found, 27 were found along the vegetated southern perimeter, and only one was found along the un-vegetated western perimeter that served as our control.

DISCUSSION

The near-absence of collisions along the completely un-vegetated western perimeter of Morgan Mail during the three-day study coupled with the numerous collisions along the vegetated perimeter (1:27) supports our hypothesis that the frequency of collisions is highest along those portions of the exterior glass surface that reflect outside vegetation. Furthermore, our comparison of collision numbers between Morgan Mail's vegetated and less-vegetated sections revealed a statistically significant disparity in collision rates of about five to two—very similar to the corresponding numbers of tall trees at each of these sections. Additionally, we recorded only four collisions along the less vegetated exteriors of the six downtown buildings that were monitored intensively during the downtown study, compared with 38 collisions at the more vegetated, and less monitored, sites of Morgan Mail and World Financial Center. Finally, the analysis of Manhattan's top 10 collision sites lends further support to our hypothesis that both reflective and transparent windows are involved in collisions at vegetated sites by clearly documenting high collision numbers at sites with extensive vegetation opposite large windows. While more research is needed to quantify the extent of collisions across Manhattan, it is likely that the majority of collisions occur at only a handful of high-collision sites that incorporate these characteristics.

Given that most collisions seem to occur at windowed exteriors that incorporate vegetation, it is not surprising that we also find extensive evidence to support our second hypothesis that most collisions occur during daytime hours. The single nighttime collision recorded during the spring downtown study, which included intense nighttime monitoring of four skyscrapers during the week of peak migration, suggests that nighttime collisions at tall urban structures may not be as pervasive as once thought. This finding also supports previous research conducted in Manhattan, which documented very few nighttime collisions at the very tall and well-lit Empire State Building (DeCandido 2005). Data from the three-day study at Morgan Mail also support our hypothesis; however, at this site, two of the factors involved in nighttime collisions were missing from this site: Morgan Mail was a low structure that emitted no artificial light. Our analysis of Manhattan’s top 10 collision sites further supports our hypothesis by showing that four of the top collision sites were low-rise buildings (<40 m), most of which were dark during the night. Additionally, the five skyscrapers on this list (>100 m) were also found to incorporate large, reflective windows opposite vegetation.

While compelling, these findings do not prove that tall, well-lit buildings do not pose a threat to nocturnal migrants passing through an urban environment. The low number of bird strikes recorded during the downtown study may simply reflect the fact that during periods with good weather and relatively clear skies, the rate of nighttime collisions at tall structures is low; a phenomenon also documented at communications towers (Cochran and Graber 1958, Avery et al. 1976). Also, the high collision numbers reported for the Twin Towers may have been partly due to the buildings’ ability to attract higher numbers of birds as a result of their extreme height (almost double the height of the next tallest skyscraper on the list) and bright lights. However, participants that monitored these buildings indicated that many of the collisions at these sites were still seen to occur during the day, and it remains unclear what proportion, if any, actually occurred during the night. It is also possible that nighttime collisions may be more prevalent in other geographic locations where wind patterns and other factors may differ.

Our research finds strike rates at high-collision sites to be significantly higher than previously reported. Other studies carried out in non-urban areas estimated about 30 collisions per year per building at various high-collision sites (Klem 1990, Dunn 1993, O'Connell 2001). At Manhattan’s high-collision sites, well over 100 collisions were recorded annually. Additional anecdotal evidence from similar sites in Toronto, Ontario and Great Neck, NY suggests that even exteriors of 40 m or less can be associated with hundreds of collisions per year (personal communication: Michael Mesure, Executive Director of FLAP; and Valerie DiNatale, Project Leader, respectively). Given that such sites can be found throughout the country, the true number of annual collisions may be higher than previously estimated.

In contrast with other research, we find that most collisions occur during spring and fall migration, involving mostly passage-migrants (Table 1). Both Klem (1989) and Dunn (1993) focused on sites with bird feeders, a fact which could have inflated the relative proportion of collisions that occur during winter. Both our results and those reported by Ogden (1996) and O'Connell (2001) indicate that sites without feeders witness significantly more collisions during spring and fall compared with summer and winter. More research is needed to accurately estimate seasonal strike rates across North America.

The increasing usage of exterior glass together with the continuing popularity of landscaping likely presents a threat to migratory bird species. Of particular worry are buildings that incorporate the characteristics of high-collision sites – large glass exteriors opposite abundant vegetation. Our findings suggest that more research is necessary to verify and document the role of such buildings in causing bird collisions, both in urban and non-urban environments. Given that our urban and suburban centers continue to expand into rural landscapes where many migratory birds can be found during spring and fall, this knowledge would prove very valuable in guiding efforts aimed at reducing bird collisions.

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Table 1: Top 20 species involved in collisions in Manhattan, 1997 – 2005.

Taxonomy follows the American Ornithologists' Union 7th Edition Check-list (2005).

Common name	**Scientific name**	**Number of collisions** 1997-2005
White-throated Sparrow	*Zonotrichia albicollis*	737
Common yellowthroat	*Geothlypis trichas*	422
Ovenbird	*Seiurus aurocapillus*	275
Dark-eyed Junco	*Junco hyemalis*	248
Ruby-crowned Kinglet	*Regulus calendula*	127
Hermit Thrush	*Catharus guttatus*	125
Song Sparrow	*Melospiza melodia*	106
American Woodcock	*Scolopax minor*	104
Black-and-white Warbler	*Mniotilta varia*	100
Gray Catbird	*Dumetella carolinensis*	95
Swamp Sparrow	*Melospiza georgiana*	85
Golden-crowned Kinglet	*Regulus satrapa*	83
Black-throated Blue Warbler	*Dendroica caerulescens*	70
Blackpoll Warbler	*Dendroica striata*	69
Northern Flicker	*Colaptes auratus*	60
Yellow-bellied Sapsucker	*Sphyrapicus varius*	56
Magnolia Warbler	*Dendroica magnolia*	52
American Redstart	*Setophaga ruticilla*	45
Brown Creeper	*Certhia americana*	45
Wood Thrush	*Hylocichla mustelina*	43

***Table 2*: Top 10 collision sites in Manhattan, 1997 - 2005.**

Location	**Number of collisions** 1997-2005	**Start date** of Monitoring	**Window size and vegetation** 1= large windows, some vegetation 2= large windows, extensive vegetation, no park 3= Large windows, extensive vegetation, near urban park	**Building height** (m)	**Artificial light emitted from building** 1 = little to no light 2 = internal light only 3 = internal and external light
Morgan Mail	470	fall 2002	3	30 (est.)	1
World Trade Center 2	438	fall 1997- fall 2001	1	415	2
World Trade Center 1	402	fall 1997- fall 2001	2	417	3
World Financial Center Winter Garden	361	fall 1997	2	38	2
World Financial Center 2	241	fall 1997	3	197	2
Jacob Javits Convention Center	115	fall 2004	3	30 (est.)	1
World Financial Center 4	104	fall 1997	2	152	2
WFC - Mercantile Exchange	96	fall 1997	2	78	2
Metropolitan Museum of Art	95	fall 2005	3	30 (est.)	1
1 Chase Plaza	83	fall 2000	1	248	2

***Table 3:* Downtown Study – Building characteristics and collision numbers, May 7-14, 2005.**

Location	**Number of collisions**	**Window size and vegetation** 1= large windows, some vegetation 2= large windows, extensive vegetation, no park 3= Large windows, extensive vegetation, near urban park	**Building height** (m)	**Artificial light emitted from building** 1 = little to no light 2 = internal light only 3 = internal and external light
1 Battery Park Plaza	0	1	151	3
17 State Street	1	1	165	2
1 State Street Plaza	1	1	140	2
3 New York Plaza	1	1	77	2
New York Telephone Company	0	No windows	30 (est.)	1
55 Water Street	1	1	209	2
Morgan Mail*	14	3	30 (est.)	1
World Financial Center*	24	3	38-197	2

* High-collision sites were added for comparison purposes.

Figure 1: **Study sites and sampling methodology, 2005.**

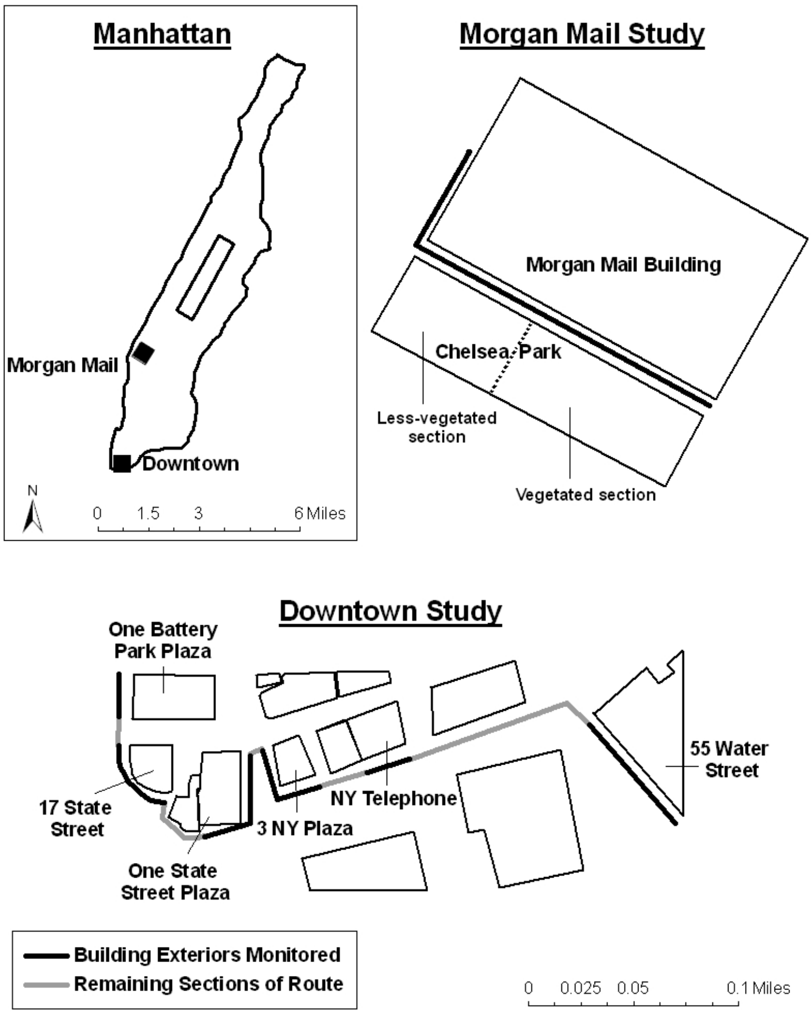
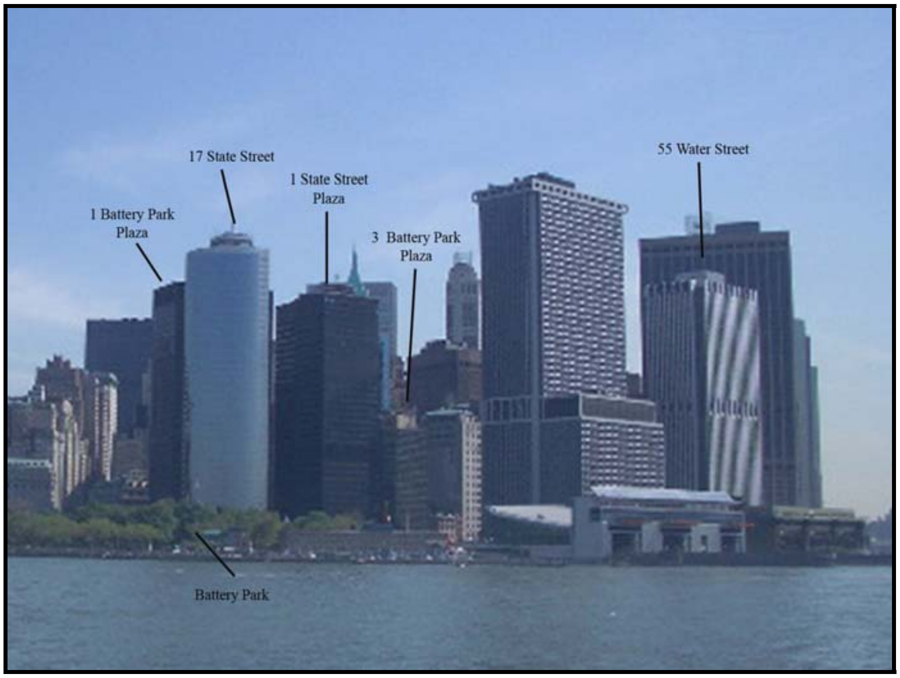


Figure 2: **Buildings monitored during Downtown Study, May 7-14, 2005.**



(Photo: Nicole Delacretaz)

Figure 3: **Weekly collision numbers, 1997-2005.**