Scientific Research Permit # 110101 **2013 FIELD SEASON REPORT**

English Holly Removal and Research in St. Edward State Park: Control of English Holly for Science and Native Biodiversity

ENGLISH HOLLY (*Ilex aquifolium*) INVASION IN SAINT EDWARD STATE PARK: 2013 REPORT

Dr. David Stokes[1], Katrina Fisk, Dr. Santiago Lopez, University of Washington, Bothell

Note: *This document reports the results of our 2013 field season and the combined results from all three field seasons (2011, 2012, and 2013) of our work on English holly in St. Edward Park. Results from the 2011 and 2012 seasons are reported in Stokes et al. (2014). This report adds the 2013 data to the data in that paper, including updating all figures with 2013 data. Where appropriate (e.g., for contextual material, and where the combined results do not materially differ from 2011 & 2012 results), we refer to the 2014 paper, which is attached as Appendix A. Results specific to the 2013 field season, updated results (prior results with 2013 data added), and sections addressing topics not covered in the 2014 paper (e.g., estimated time requirements for clearing holly) are presented in this report.*

[1] Address questions and comments to dstokes@u.washington.edu

ABSTRACT

We located and removed all English holly plants from a 0.8 hectare (2 acre) area of St. Edward State Park in February – May 2013. The sample was combined with previous years' (2011 and 2012) samples for a combined sample area of 9.2 hectares (22.8 acres). Removal was accomplished by uprooting when possible, and cutting at ground level the trees that were too large to be uprooted. A total of 65 holly plants (avg. of 44.6 per acre) that were > 1 cm basal stem diameter or ≥ 1m from their nearest conspecific were located and removed in 2013, making a total of 532 sampled holly plants in the combined three-year sample.

We collected a ground level cross section from each of the sampled trees, allowing us to determine their ages, which ranged from 1 to 46 years in the combined sample. We found no dead holly plants. The oldest trees in our sample exceeded 10 m in height and 15 cm basal stem diameter. Holly trees in our sample were in the rapid growth stage of their life history, as reflected by steepening height-age, stem diameter-age, and canopy area-age curves. Native shrub and ground cover vegetation was much sparser and less diverse under holly canopy than in adjacent areas.

Mapping and aging of the holly plants indicated that the species is spreading rapidly in St. Edward Park. Spread occurs at two scales: contiguous expansion of clumps of trees, primarily vegetatively, and long distance dispersal, probably via animal-dispersed seed. The pattern of spread through time appears to reflect both of these mechanisms, with clumps of holly expanding outward, and new clumps becoming established throughout the study area over the last 40 years. Spread by both mechanisms appears to be accelerating. Thirty-six percent of our sampled trees originated from seed, and seed establishment appeared to be increasing rapidly. The time of establishment of the oldest trees in our sample, the late 1960's, is shortly after much of the residential development occurred along the north border of St. Edward Park. This, the apparent concentration of holly near the north end of our sample area, and evidence of prolific establishment of young holly from seed in the 2013 sample, suggest that the original seed source for the holly invasion may have been ornamental trees planted by early neighborhood residents.

Results over the three year study indicate that English holly is increasing exponentially at St. Edward Park, and has the potential to become, within a few decades, a dominant species both in number of individuals and area occupied. Preliminary results indicate that holly establishes well under heavy shade, and may establish preferentially under evergreen canopy, which is common in forests of St. Edward Park and western Washington generally.

The emergence of holly as a dominant species would likely come at the expense of native plant diversity and could have large effects on the native forest ecosystem. This is particularly problematic for St. Edward Park, which is one of the few exemplars of relatively intact native Pacific Northwest west-side forest in the Seattle metropolitan region. We present preliminary data on the effectiveness of the holly control methods used in this study, and we provide an estimate of the time and labor requirements for removal of holly from all St. Edward Park forest. We also present a research agenda that could produce information necessary to inform the management of this species. Maps and figures of the course of holly spread, such as we provide here, may be useful in conveying to the public the seriousness of holly invasion, and invasion by non-native species generally.

INTRODUCTION

See Introduction from Stokes et al. (2014), attached (Appendix A).

Study Area: Saint Edward State Park

See Study area description from Stokes et al. (2014), attached (Appendix A).

2013 Addendum:

In 2013, we sampled an area of 0.8 ha (2.0 acres), bringing the total (2011 – 2013) study area to 9.2 ha (22.8 acres). See Fig. 2. Additional details below in Methods section.

Figure 1. St. Edward State Park and environs. Dominated by primarily native semi-mature forest, the park (border indicated by yellow line) is largely surrounded by residential development. Aerial photo from Smith (2006).

METHODS

See Methods from Stokes et al. (2014), attached (Appendix A).

2013 Addendum:

From February – May 2013, our field team (Appendix B) surveyed a 0.8 ha (2.0 acre) area in St. Edward State Park for English holly, using the same methods (Apendix C) used in the previous two field seasons (Fig. 2). The 2013 sample area was contiguous with the western border of the previous year's sample area, and was in the same forest community type as previous sample areas (Smith 2006). The addition of the 2013 sample brings the total study area size to 9.2 ha (22.8 acres). Within the 2013 sample area near the north edge, was a small (150 m^2) area that had been highly disturbed by humans, where there had been heavy trampling, cutting of vegetation, and piling of wood. Numerous small (< 1 cm basal diameter) holly were present. Because of the level of anthropogenic disturbance, which is unrepresentative of the natural forest, we excluded this section from the study area and excluded the holly plants (n = 18; basal diam. 0.1 – 0.6 cm) found there from our combined sample.

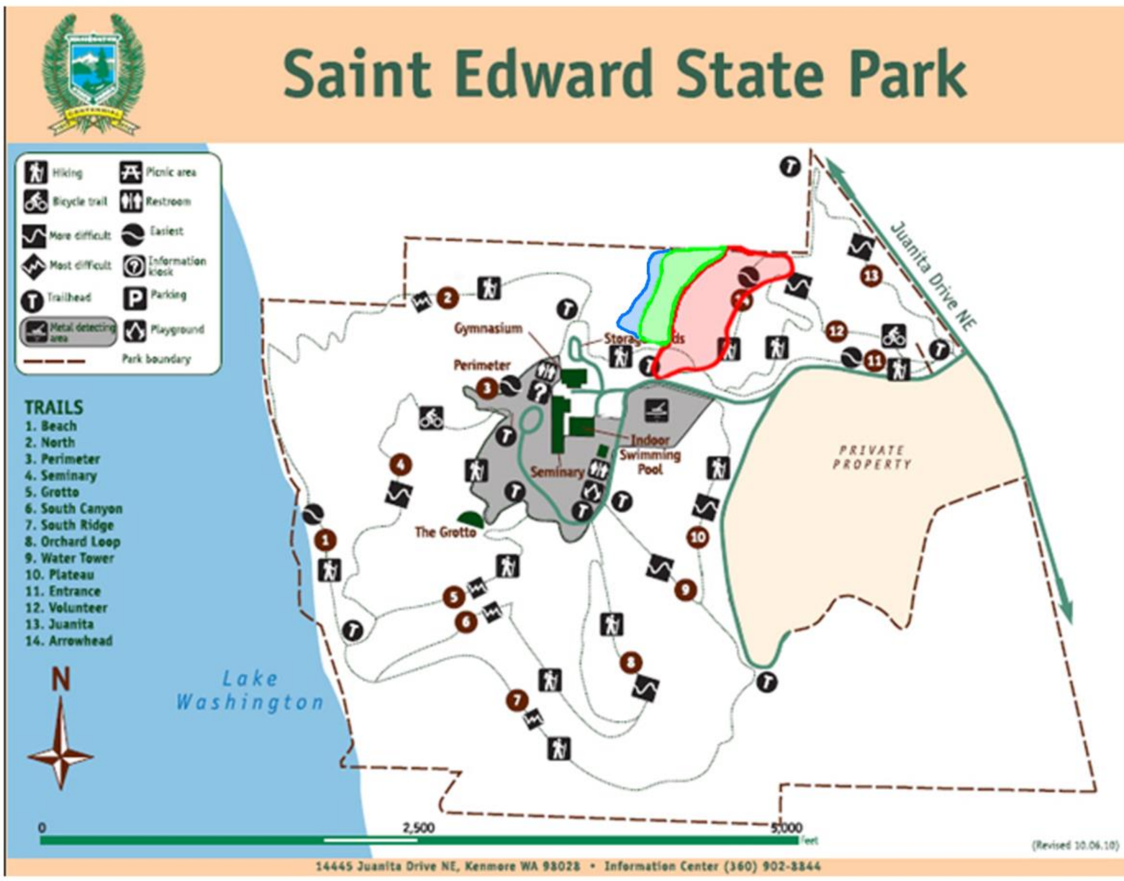

Figure 2. Approximate location of English holly study area at St. Edward State Park. Study area was sampled in sections over three years: 2011 (red), 2012 (green), and 2013 (blue). Along the north edge of Park and study area is a residential neighborhood, with most homes constructed in the 1950's to the 1970's, and an elementary school and grounds established in 1957. 2010 Washington State Parks map.

RESULTS AND DISCUSSION

See Results and Discussion from Stokes et al. (2014), attached (Appendix A).

2013 Addendum:

Note: all results, including figures, are updated here to include the 2013 data.
Relative to the sample from 2011 and 2012, the 2013 sample was characterized by much smaller, younger trees, with a higher proportion of plants originating from seed (as opposed to vegetative spread).

English holly in St. Edward Park

In 2013 we located, sampled, and removed a total of 65 holly trees in our 0.8 ha (2.0 acre) study area, or approximately 81.3 trees/ha (33.4 trees/acre). We also removed 112 sprouts. We removed an additional 18 small holly plants and 10 sprouts from the small (150 m^2) heavily disturbed area; these were excluded from our sample.

In the total combined (all years) study area of 9.2 ha (22.8 acres), we located, sampled and removed 532 holly trees (57.7 trees/ha; 23.4 trees/ha; Table 1), and approximately 760 unsampled small sprouts (82/ha; 33/acre), for a total holly stem density (sample trees plus unsampled sprouts) of approximately 140 stems/ha (57 stems/acre). Of the total sampled trees, 160 trees (17.4/ha; 7.0/acre) were ≥ 10 years of age. Unsampled sprouts had a basal diameter ≤ 1 cm and were within 1 meter of a sampled tree. They were likely very young; average age of sampled trees in this size range (basal diameter < 1 cm) was 3.84 years (sd = 2.20, n = 318). Six (1.9%) of the 318 sampled trees with basal diameter < 1 cm were ≥ 10 years old (all aged 10 – 12 years).

Of the 65 trees sampled in 2013, we were able to remove all by uprooting. Of the 532 trees in the in the combined sample, we removed 487 (92%) by uprooting by hand or using a weed wrench. The remaining 45 were cut at the base, with herbicide applied to the cut stumps of 29 of the 45. The maximum basal diameter of trees removed by uprooting was 7.1 cm. The minimum basal diameter of trees that could not be removed by uprooting was 3.5 cm. Nineteen (50%) of the 38 trees with basal diameter ≥ 3.5 cm and ≤ 7.1 cm could be uprooted.

Holly in St. Edward State Park appears to have a very low mortality rate. We found no dead holly in 2013, and over the three years of our study, surveying 9.2 hectares and 532 holly plants, we have not found any dead holly trees despite the fact that leaves of dead holly trees remain attached and recognizable > 1 year (*pers. obs*.), and therefore trees that had died in the last year or more would be readily noticeable.

Nearly all sampled holly plants appeared to be healthy, with deep green foliage showing little evidence of disease or herbivore damage. Twenty-two (4.1%) of the 532 sampled trees showed damage from falling trees or limbs: six had broken trunks, and 16 were bent over and pressed to the ground or nearly so. All of these 22 except one had thick healthy-looking foliage. The only holly tree in our sample that did not appear healthy was a 16 year-old tree that appeared to have been pinned for many years by a fallen tree. It had thin, yellow-green foliage. Most of the bent-over trees showed rooting from limbs that had been brought into contact with the ground.

Table 1. Number, density, age, and size of sampled English holly in St. Edward State Park study area.

a. 2013 sample (0.8 ha; 2.0 acres).

Sample	N	Density (ha^{-1})	Age (yrs) avg (SD)	Age (yrs) range	Basal diam. (cm) avg (SD)	Basal diam. (cm) range	Height (m)* avg (SD)	Height (m)* range	Crown diam. (m)* avg (SD)	Crown diam. (m)* range
All	65	81.3	5.9 (5.9)	1 – 15	0.7 (0.5)	0.1 – 3.1	0.6 (0.4)	0.1 – 1.8	0.2 (0.2)	0.1 – 1.2
≥ 10 yrs	9	11.3	11.9 (1.8)	10 – 15	1.4 (0.7)	0.6 – 3.1	1.1 (0.5)	0.6 – 1.8	0.6 (0.3)	0.4 – 1.2
< 10 yrs	56	70.0	4.9 (2.2)	1 – 9	0.5 (0.3)	0.1 – 1.6	0.5 (0.5)	0.1 – 1.4	0.2 (0.1)	0.1 – 0.7

** Trees for which height (n = 3) or canopy diameter (n = 2) was not determined are excluded from averages for those measures.*

b. Combined sample (9.2 ha; 22.8 acres); trees sampled in 2011, 2012, and 2013.

Sample	N	Density (ha^{-1})	Age (yrs)** avg (SD)	Age (yrs)** range	Basal diam. (cm) avg (SD)	Basal diam. (cm) range	Height (m)* avg (SD)	Height (m)* range	Crown diam. (m)* avg (SD)	Crown diam. (m)* range
All	532	57.7	8.4 (7.9)	1 – 46	1.8 (3.2)	0.1 – 35.0	1.5 (1.9)	0.1 – 18.0	0.7 (1.0)	0.1 – 10.5
≥ 10 yrs	160	17.4	18.2 (7.7)	10 – 46	4.5 (4.8)	0.6 – 35.0	3.3 (2.7)	0.5 – 18.0	1.7 (1.4)	0.2 – 10.5
< 10 yrs	372	40.4	4.1 (2.2)	1 – 9	0.7 (0.4)	0.1 – 3.3	0.7 (0.5)	0.1 – 3.0	0.2 (0.2)	0.1 – 1.3

** Trees for which height (n = 15) or canopy diameter (n = 10) was not determined are excluded from averages for those measures.*

*** Age could not be determined for 3 small individuals.*

Trees in the study area ranged from 1 to 46 years of age, with many young individuals and declining numbers of older ages (Fig. 3). Seventy percent (n = 372) of sampled trees were less than 10 years old in the year they were surveyed. Within this general pattern of declining numbers with age, there was variability in representation of ages, with anomalously low numbers of some ages (e.g., trees established in 1998 & 1999, 2001-2003), and high numbers of others (e.g., established in 1996, 1997, 2000, 2005, 2009). These anomalies may reflect unusually unfavorable and favorable establishment conditions in some years.

Of the 308 holly plants for which reproductive mode of origin could be determined, 197 (64%) established vegetatively from holly roots or branches, and the remaining 111 (36%), established from seed. It should be noted that the 2013 sample (n = 65) had a much higher proportion (92%) of seed-established plants than the previous years' samples (21%). Much of the 2013 sample consisted of very young plants located at the north end of the study area near some very large berry bearing trees associated with local residences. This may be an anomalous location for seed establishment, either because of heavy propagule pressure or favorable seed establishment conditions. We suspect that mortality of very young holly may be higher than older holly, and it is possible that mortality of these young holly plants may result in fewer older seed-established plants in this location in the future.

Notwithstanding the high proportion of seed-originated holly in the small 2013 sample, with most of the sampled holly trees in our study area originating vegetatively (in addition to nearly all of the unsampled sprouts), it is clear that vegetative spread is responsible for most of the holly plants in the invading population. Nonetheless, the greater capacity for long-distance spread via seed makes seed-originated holly an important component of the invasion, accounting for all spread into unoccupied habitat. Number of yearly seed establishment events was variable, but generally increased since the start of the invasion (Fig. 5a), resulting in a cumulative population of seed-originated trees that increased sharply (Fig. 5b) as the number of seed bearing trees in the area grew.

Given the large number of berries produced by a holly tree (Peterken and Lloyd 1967, *pers. obs*.), the vast majority of seeds do not establish. The annual variability in seed establishment (Fig. 5a) suggests that holly's rate of establishment is not solely a function of the number of trees in the area, and may also be related to variability in any of several factors, including weather conditions, seed predator or disperser populations, and pollen availability.

The height of holly trees in the study area ranged from 0.1 m to 18 m, with an average of 1.5 m (sd = 1.95, n = 514; Fig. 6). Tree height (Fig. 7) and diameter at base (Fig. 8) were positively correlated with age. Both height-age and basal diameter-age curves became progressively steeper with age, indicating that in the environment at St. Edward Park the age range of trees in our sample is a period of accelerating biomass accumulation. The oldest holly plant in the study area (46 years), a large multi-trunked tree, also had the largest stem diameter (35.0 cm basal diameter). A 30-year old tree had the largest dbh (11.1 cm). These values are well below the maximum height and stem diameter observed in the species' native range (13 - 24 m height and >64 cm dbh, Peterken and Lloyd 1967), suggesting that holly trees in St. Edward Park have the potential for considerable future size increase.

Like height and stem diameter, canopy diameter (Fig. 9) also grew at an increasing rate with age in the age range of our sample trees. Area covered by tree canopy ranged from 0.01 m^2 to 86.6 m^2 for the oldest tree in the sample. The average size of the holly sampled in 2013 was considerably smaller than the previous years' samples by all size measures (Table 1).

English holly is dioecious; only female trees produce berries (Peterken and Lloyd 1967). The small proportion of mature trees in our sample that had berries (14 of 100 trees 15 years or older; Figures 10a & b) suggests the possibility of a skewed sex ratio. Reports of holly in its native range differ on the question of sex ratio, with some studies indicating an even sex ratio (e.g., Peterken and Lloyd 1967), and others finding males outnumbering females (Richards 1988). However, as flowering and berry production in holly appears to be dependent not only on age (Peterken and Lloyd 1967), but also on size and light conditions (Richards 1988), it may be that trees without berries cannot be reliably assumed to be male. Given the extremely skewed apparent sex ratio of our sample, and the implications of such a skewed sex ratio for holly dispersal and, hence, management, the question of sex ratio of holly at St. Edward Park merits further investigation.

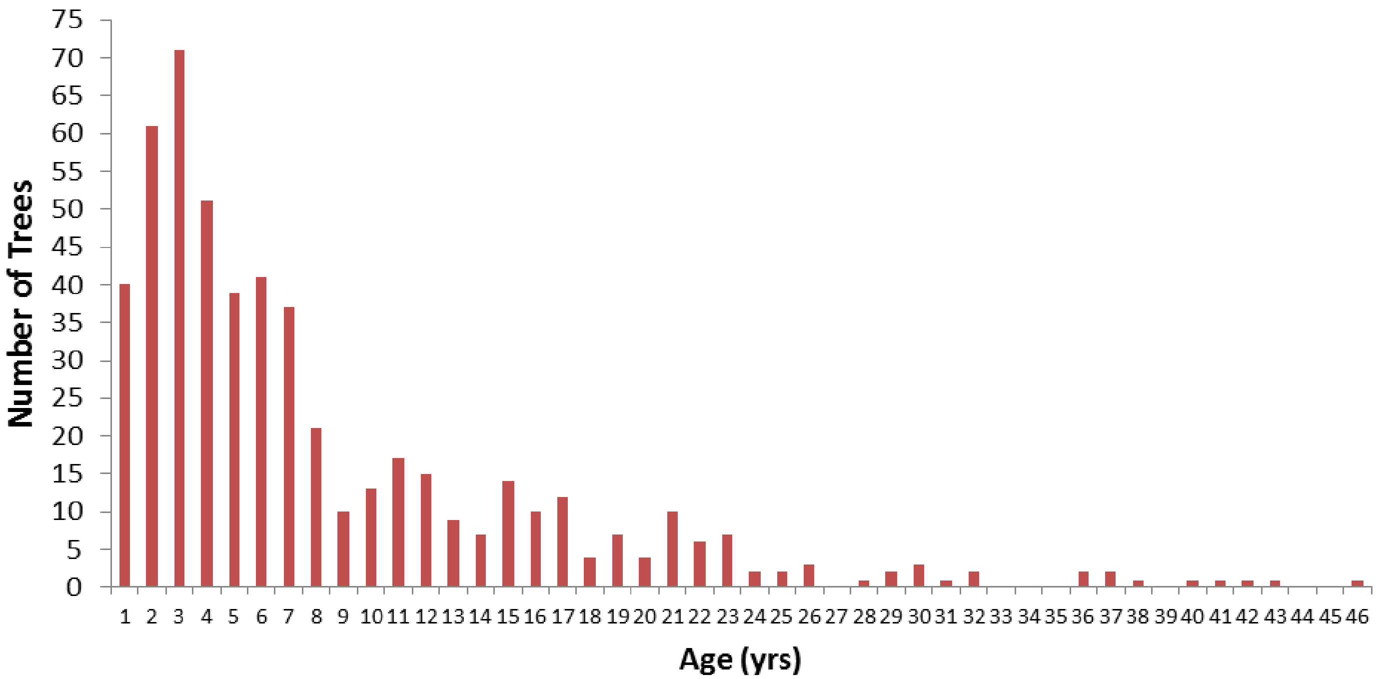

Figure 3. Ages of sampled *I. aquifolium* (n = 532) in St. Edward State Park combined (2011-2013) sample area. All holly trees in the study area ≥ 1 cm in basal diameter or > 1 m from nearest sampled tree were sampled. Three small trees could not be aged; their ages were modelled using the basal diameter-age relationship (Fig. 8). Young trees are underrepresented because small sprouts (< 1cm basal diameter) within 1 m of sampled trees were not sampled (see text).

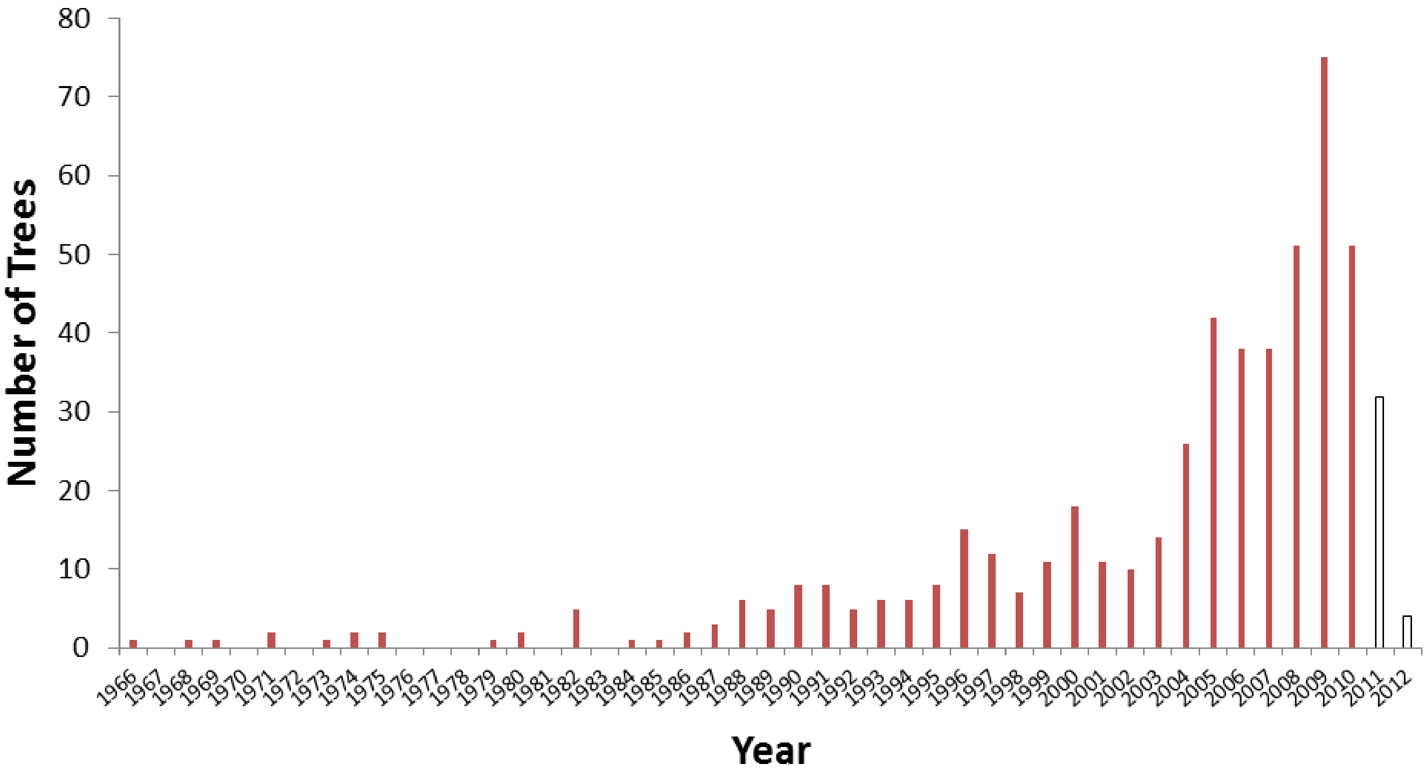

Figure 4. Year of establishment of English holly (n = 532) in St. Edward State Park sample area. Data collected in 2011, 2012 and 2013. Three small trees for which age could not be determined were assigned the mean age for their basal diameter. Young trees are under-represented due to incomplete sampling of small sprouts under sample trees. All values based on combined study area except for years 2011 (from 2012 and 2013 sample areas only) and 2012 (from 2013 sample area only).

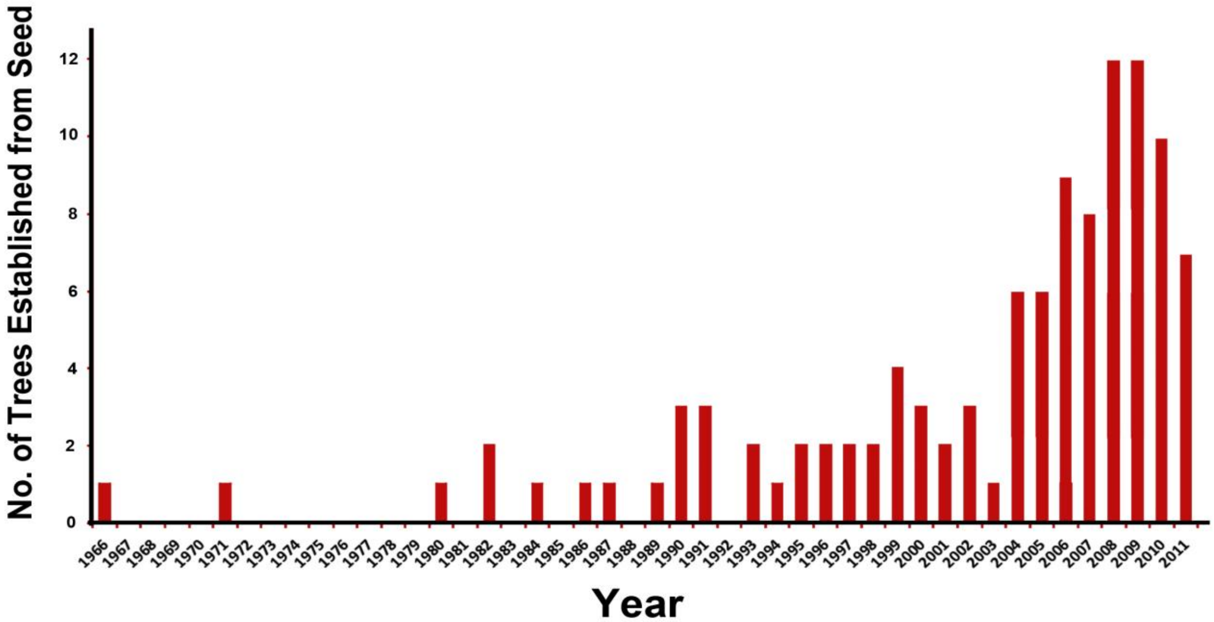

Figure 5a. Establishment of *I. aquifolium* resulting from seed (n = 111 as of 2012) in a 3.1 ha (7.7 acre) in the 2012 and 2013 sample areas in St. Edward State Park. Establishments in recent years are probably undercounted because of incomplete sampling of small sprouts under sampled trees. While most of these sprouts were of vegetative origin, a small proportion may have originated from seed.

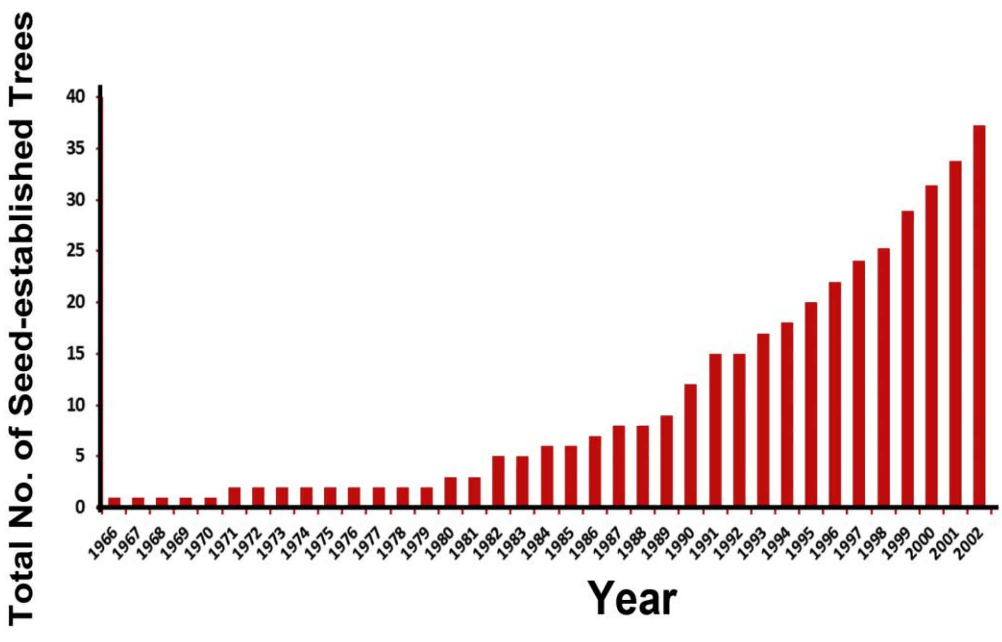

Figure 5b. Cumulative number of *I. aquifolium* resulting from seed (n=37), 1966 to 2002 in 3.1 ha (7.7 acre) St. Edward Park study area (2012 & 2013 only). Years after 2002 excluded because of incomplete sampling of small trees.

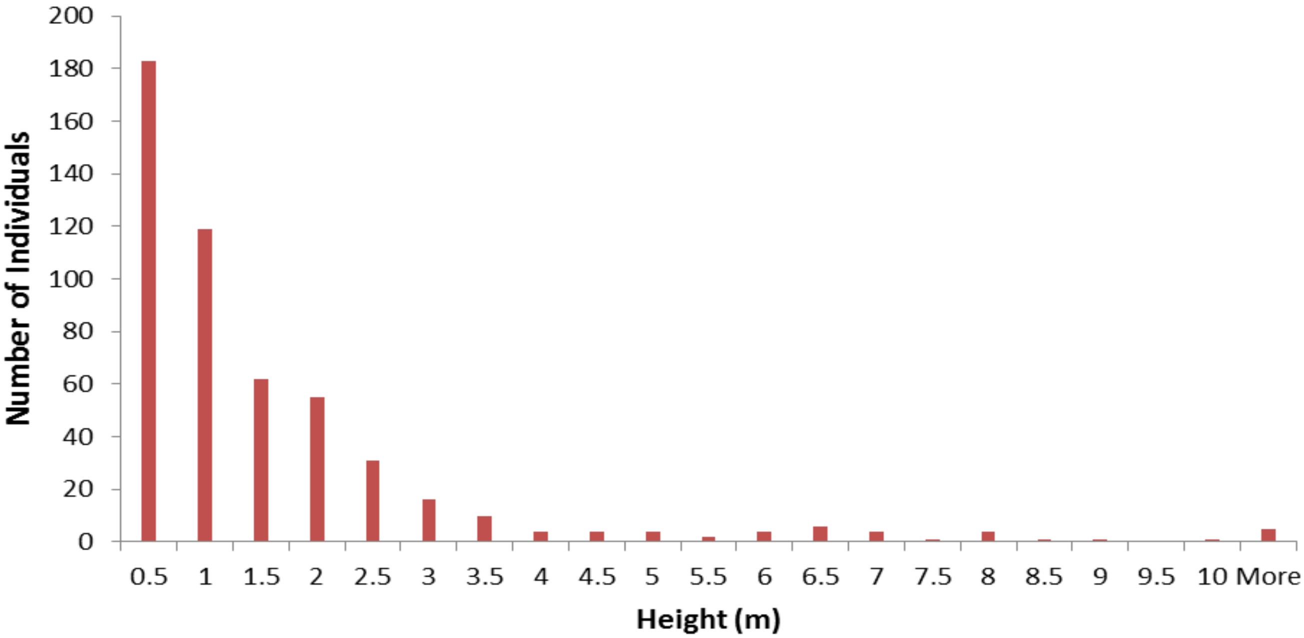

Figure 6. Heights of sampled *I. aquifolium* in St. Edward State Park combined (2011-2013) study area (n = 517). Fifteen previously cut or broken trees excluded.

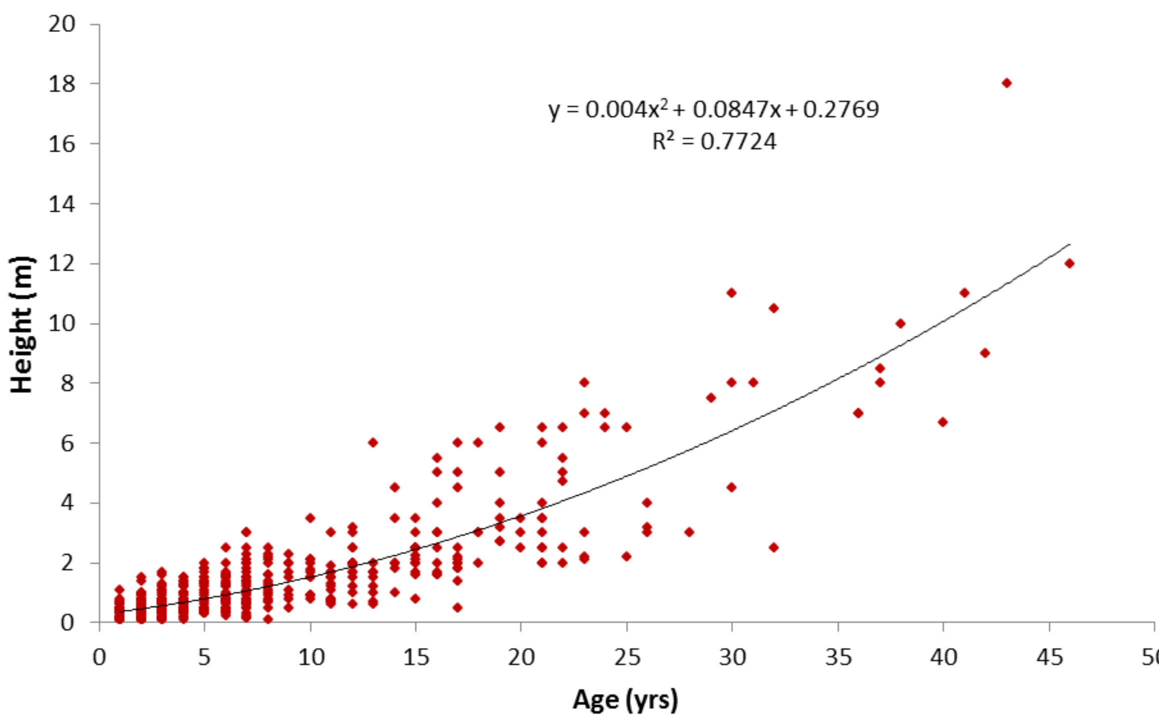

Figure 7. *I. aquifolium* height by age (n = 514) in St. Edward State Park combined (2011-2013) study area. Fifteen trees previously cut or broken and three trees that could not be aged excluded.

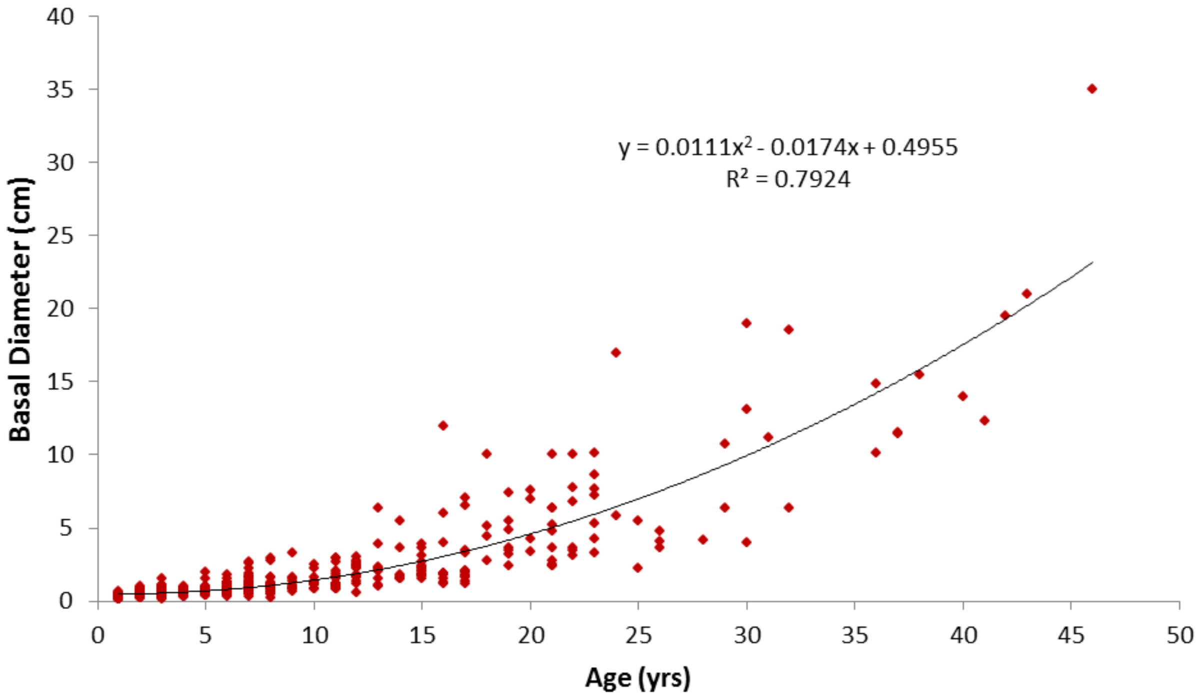

Figure 8. *I. aquifolium* stem diameter at base by age (n = 529) in St. Edward State Park combined (2011-2013) study area. Three trees that could not be aged are excluded.

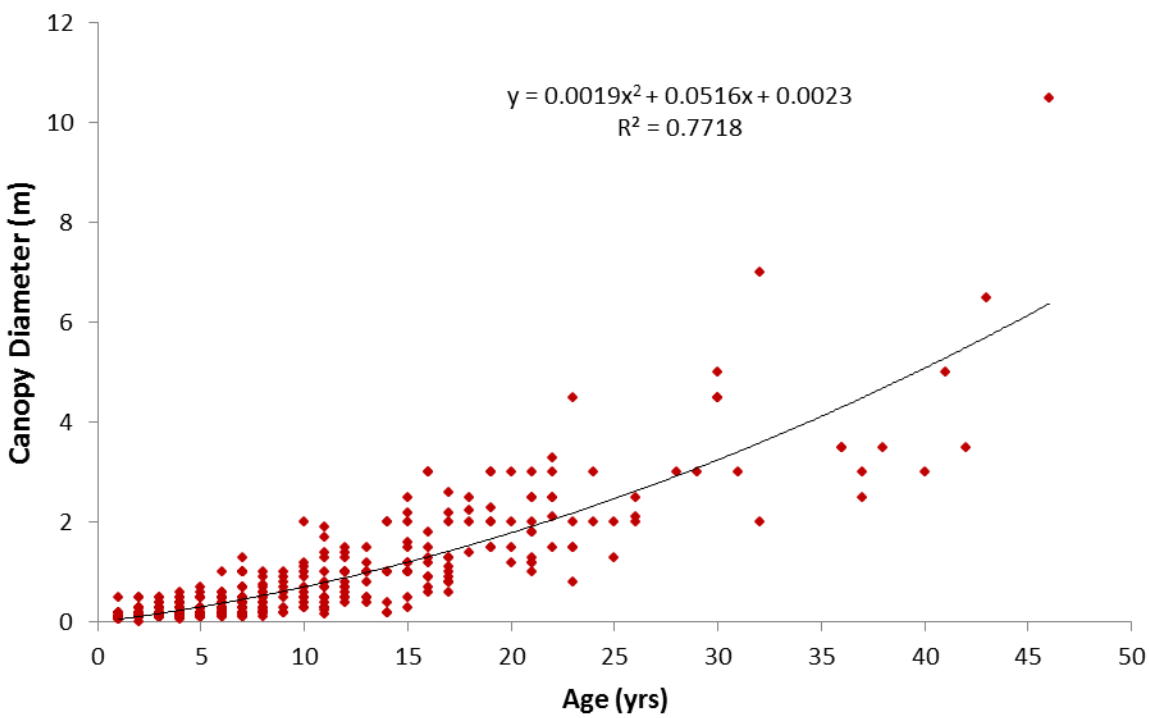

Figure 9. Canopy diameter of *I. aquifolium* (n = 518 trees) in St. Edward State Park combined (2011-2013) study area. Eleven trees with no canopy measurement (e.g., previously cut) and three trees that could not be aged excluded.

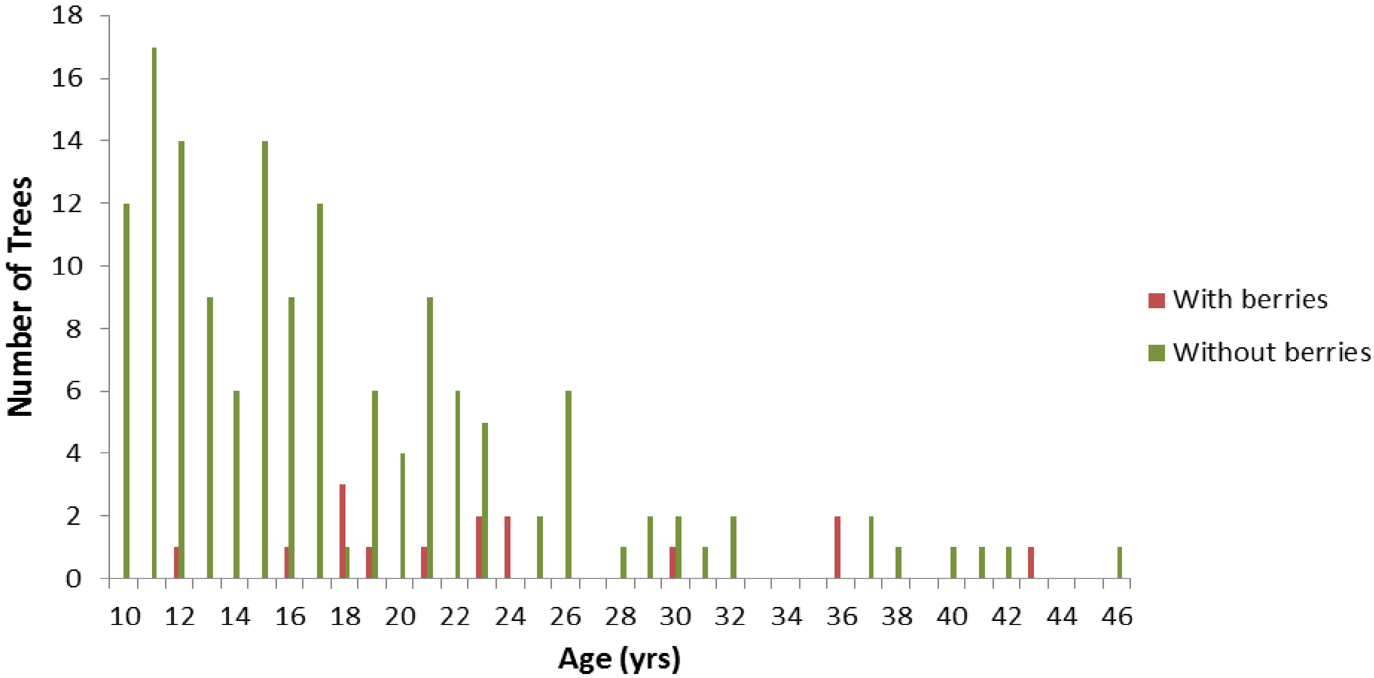

Figure 10a. *I. aquifolium* trees with and without berries by age in St. Edward State Park combined (2011-2013) sample area. (n = 160 trees ≥ 10 years of age).

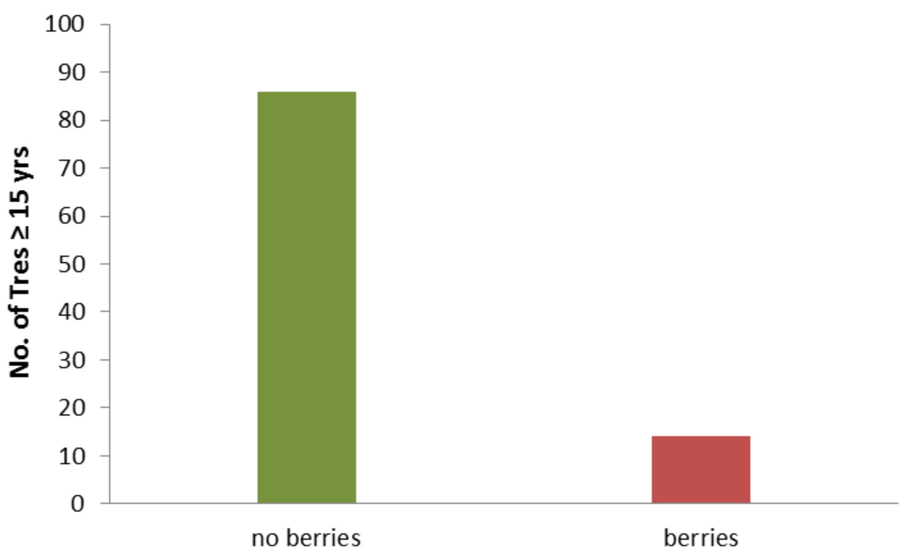

Figure 10b. Number of *I. aquifolium* ages 15 years or older (n = 100) with and without berries in St. Edward State Park combined (2011-2013) sample area. Holly is dioecious; only female trees produce berries.

Effects of English holly on native species

No additional results on this topic in 2013. We are currently analyzing data from previous years. See 2012 Report (Stokes, Church, Cronkright and Lopez 2012) for previous results. Summary paragraph and figure included here:

Native vegetation under English holly canopy was much sparser and less diverse compared to surrounding vegetation. At 33 study-area holly trees or groups of holly ("holly clumps") we compared vegetation under the holly canopy with the vegetation in the adjacent area (For list of species present see Appendix D). The total amount of native vegetation cover was dramatically reduced under holly canopy, with an average of 79% of the area under holly devoid of native ground cover, versus 36% in the surrounding area (Fig 11). Substantial areas without native vegetation occurred under large clumps of holly. For example, holly sprouts constituted the only ground cover in an area of approximately 60 m^2 under the largest holly clump in our study area (see below and Fig. 14).

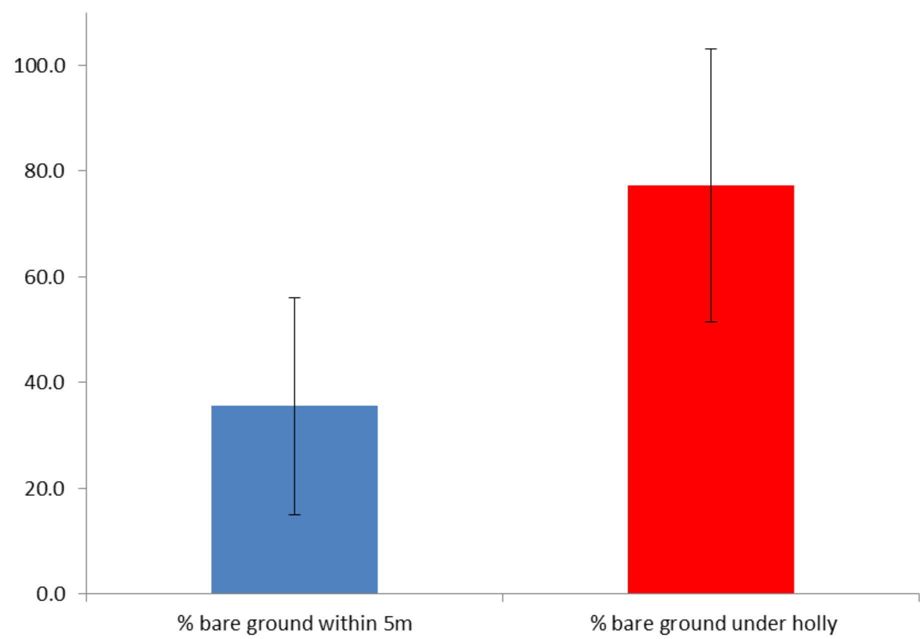

Figure 11. Mean percent ± 1 SD of area not covered by native fern, shrub, or vascular ground cover under and adjacent to English holly trees at 33 paired comparison sites. Proportions under and adjacent to holly differed significantly (paired t-test on arcsin-transformed values ($t = 10.08$, $df = 32$, $p < 0.001$).

Dispersion of holly and holly spread

The 532 holly trees in our sample occurred at variable density across the study area (Figure 13). Higher densities seemed to be located in the northern portion of the study area and along the southern edge. The overall dispersion pattern of the trees was strongly clumped, a pattern that would be even more pronounced if the 760 small sprouts within 1 m of our sampled trees were included.

Clumps of holly consisted of trees of different ages and appeared to result from one or more founder trees producing additional neighboring individuals (Figure 14). Most of the trees within clumps, including the unsampled sprouts, were the result of vegetative spread and had root systems that were connected to older trees. Clumps appeared to spread by radiation generally outward from the oldest trees in the clump. We also observed linear expansion of clumps resulting from the fall of a dead tree or limb onto a holly tree. When a holly tree was pressed lengthwise along the ground, its branches formed vertically standing trees, and rooting occurred from branches in contact with the ground.

Trees that originated from seed were widely dispersed across most of the study area (Fig. 15). The presence of young seed-originated trees in previously unoccupied locations indicates that establishment from seed is ongoing and is an active mode of holly spread.

Thus, the spatial distribution of holly in the park is a product of both long-distance seed dispersal, resulting in widely spaced clump locations, and localized vegetative spread and perhaps seedfall leading to outward spread of clumps. Both processes, seed dispersal and vegetative spread, appear to be active. Young individuals resulting from seed—potentially the founders of future clumps—were found far from other holly trees, and most existing clumps included very young individuals, indicating ongoing expansion of clumps.

Assuming that very little mortality of mature holly trees has occurred at our study site (see below), it appears that English holly has become a much more prominent component of the forest at St. Edward Park in recent decades (Fig. 16 a-d). In the space of little more than 40 years, holly has increased in our study area from a very small number of very small trees (2 trees in 1971) in one location, to 532 trees, some of which are relatively large, distributed widely over the study area.

2013 Addendum:

A large number (n = 43) of very young (avg. age = 5.2 yr, SD = 3.5, max = 10, min = 1) mostly (93%) seed-originated holly trees were located in the northwest corner of the study area in the 2013 sample area (Fig. 13). Eighteen additional small seed-originated holly were found in the nearby small, heavily disturbed area excluded from the sample. All of these small trees were within 100 m of four very large holly trees with heavy berry crops located at the edge of the yards of private residences just north of the 2013 study area (Fig. 13). Numerous additional (not sampled) small holly were present between the study area boundary and the large berry bearing holly trees.

Holly invasion and forest type

To determine if vulnerability to holly invasion varies by forest type, in 2013 we examined holly distribution in deciduous and evergreen coniferous forest within our 2011 and 2012 study areas (Appendix E). Field work was conducted by Katrina Fisk and

Joanna Mead, under the direction of Drs. Stokes and Lopez. Based on canopy measurements taken at 60 random locations in the study area, average conifer canopy for locations where holly had been (prior to removal in 2011 & 2012) present (n = 12) was significantly higher than the average for locations where holly was absent (n = 48). In addition, using canopy data collected at the time holly were removed, total average winter tree canopy cover (i.e., mostly evergreen conifer) was significantly greater (average = 70%) at sites where holly was present (n = 30) than at the 60 random study area locations (average = 42%). These results suggest that holly establishes and persists well under evergreen canopy and therefore may be a potential invader of mature Pacific Northwest forest, perhaps including undisturbed native old growth forests, a possibility with important conservation implications. These results are preliminary, and we will be conducting further research on this question in the coming year.

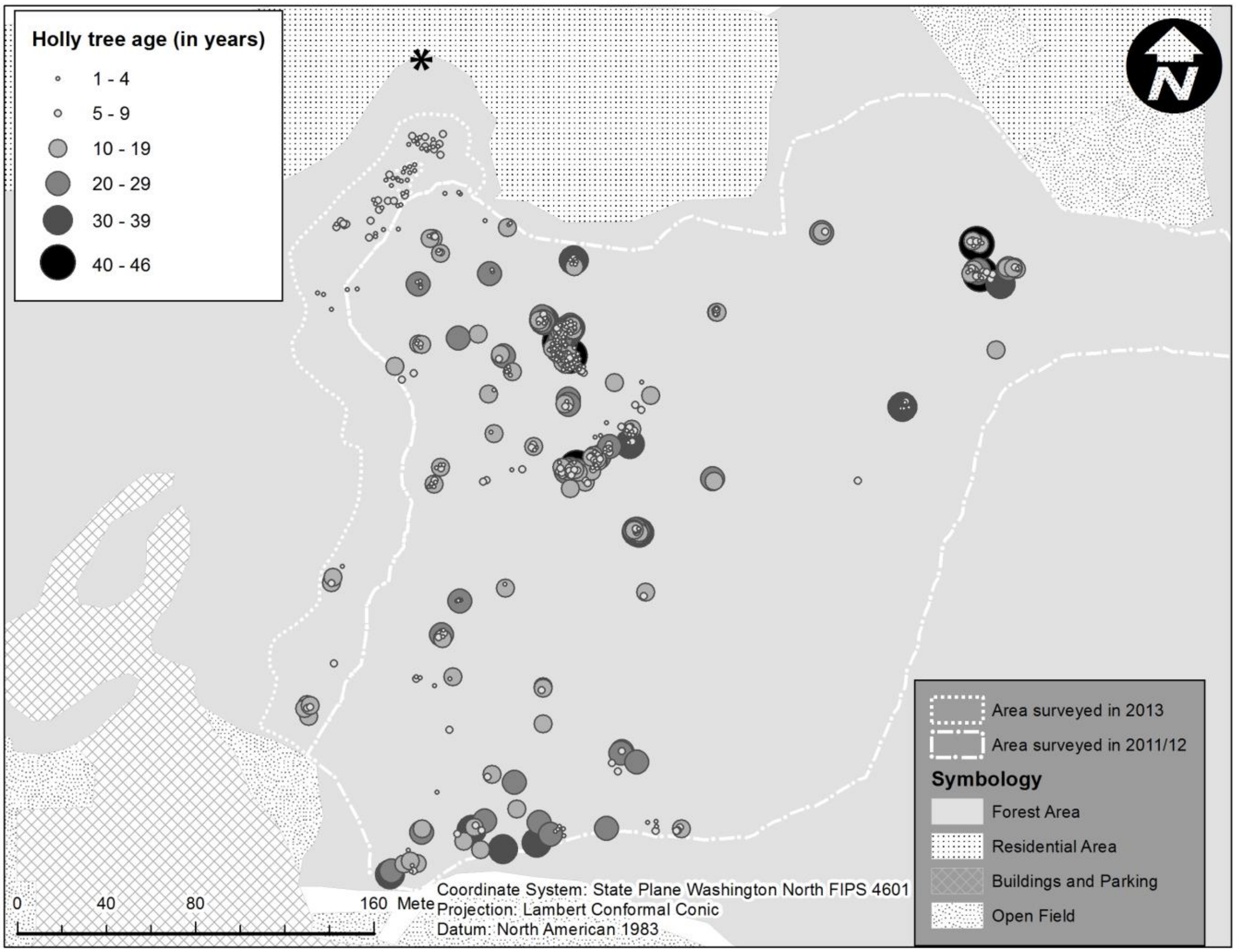

Figure 13. Spatial distribution and age of all (n = 532) *I. aquifolium* sampled and removed in the St. Edward Park study area during the 2011-2013 field seasons. Ages of three small trees that could not be determined from rings were modeled based on basal diameter (modeled ages = 4, 8, and 9 years). ***** indicates location of four large holly trees with berry crops outside of study area. 18 holly in excluded area also shown.

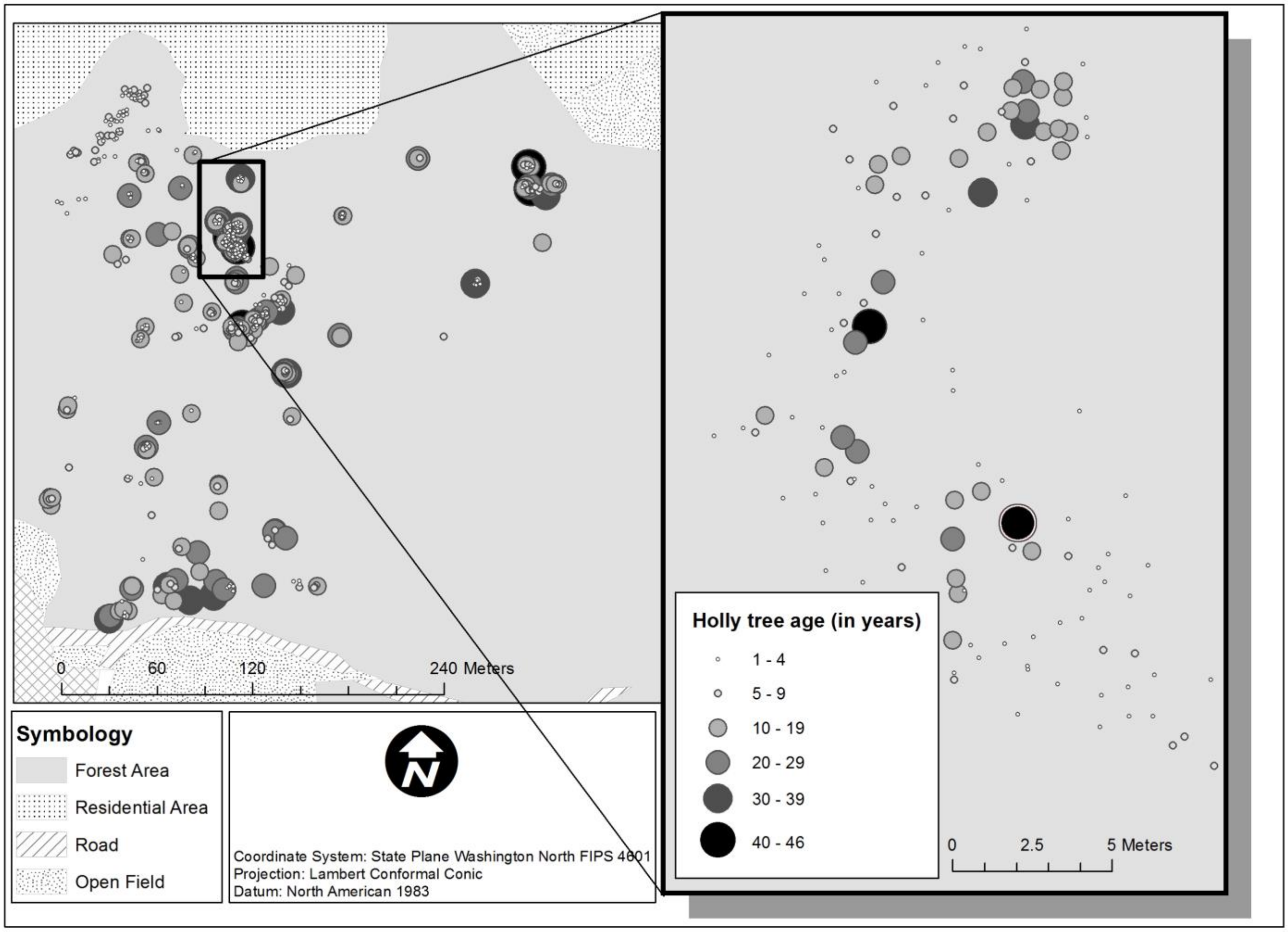

Figure 14. *I. aquifolium* dispersion and age within a clump (n = 131 sampled trees). Oldest tree (46 years) indicated by ring. Approximately 280 additional unsampled small (basal diameter $\leq$ 1 cm) sprouts were present under the canopy of trees in the clump. Ground and shrub layer vegetation cover in the clump was > 99% *I. aquifolium*. Rectangle in inset map indicates location of clump in study area.

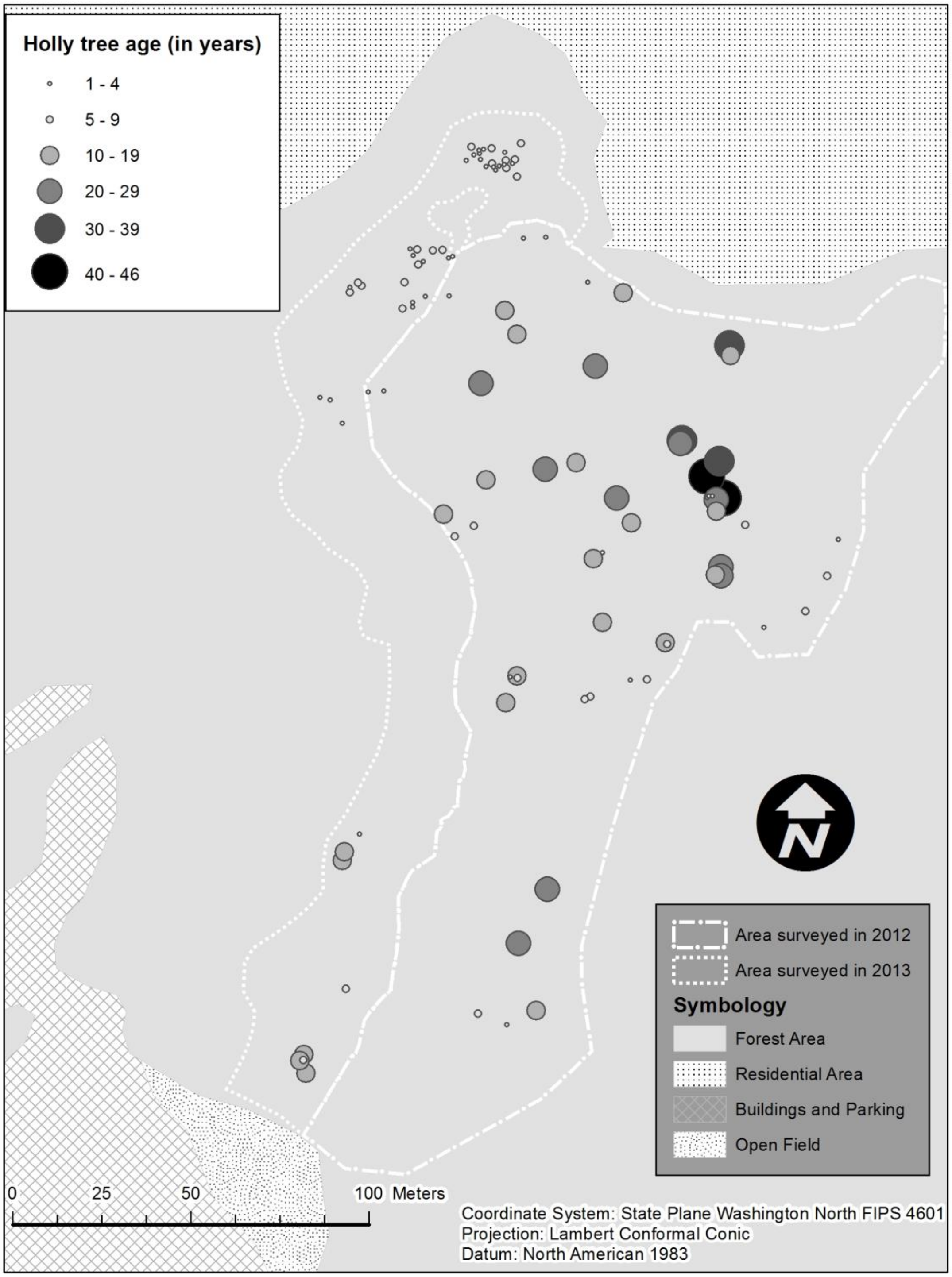

Figure 15. Location and age of seed-established *I. aquifolium* (n = 111) in the St. Edward Park study area (2012 & 2013 study area only).

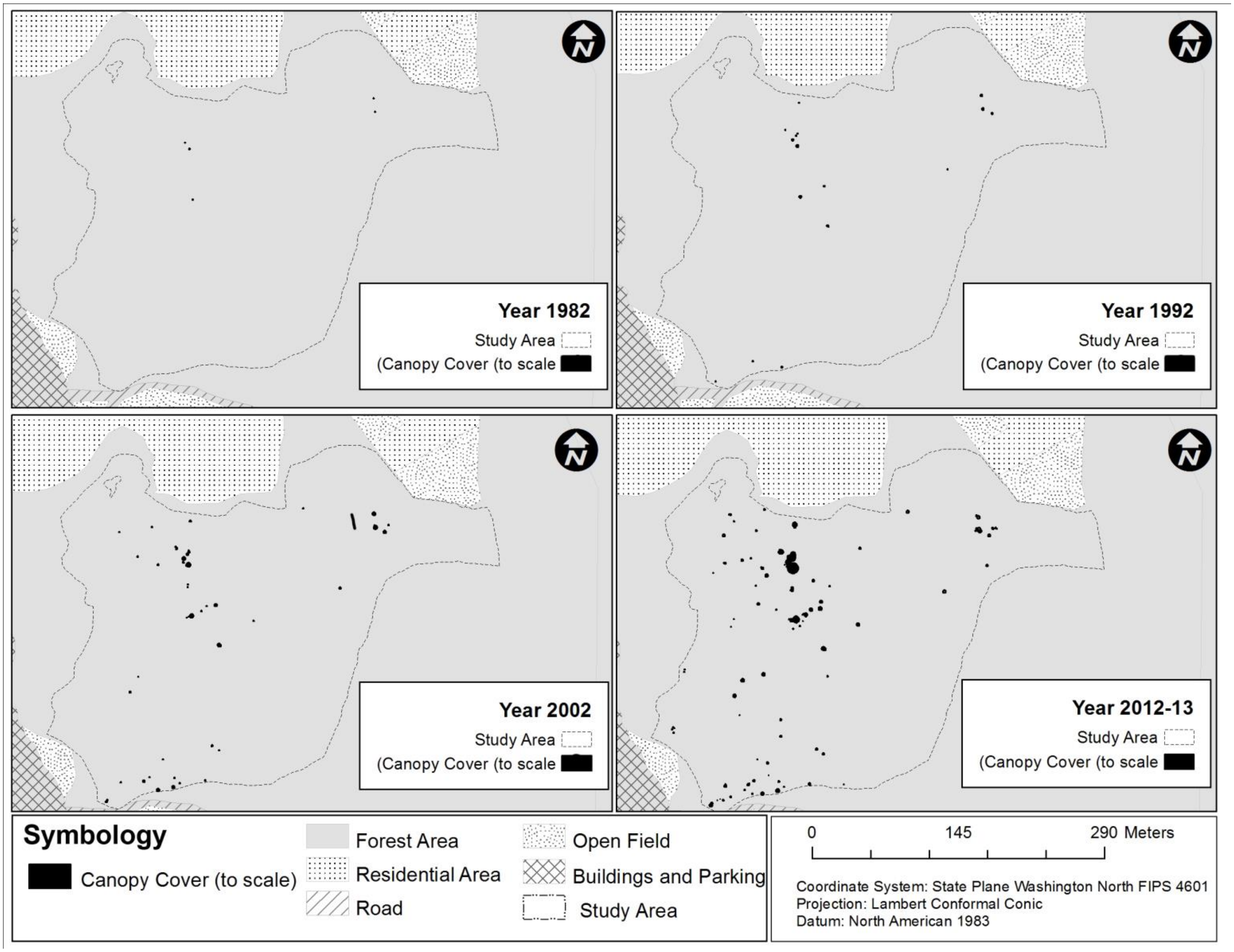

Figure 16 a-d. Past and current spatial extent of English holly canopy in St. Edward study area at 10 year intervals. Canopy depicted at actual size. Past canopy area modeled from canopy radius – age relationship (see Fig. 9).

Depiction and model of past and future holly invasion at St. Edward Park
See "Holly Population Change and Spread" from Stokes et al. (2014), attached (Appendix A).

2013 Addendum:
Addition of the 2013 data did not materially change the population growth model presented in Stokes et al., except that the fit of the data to an exponential model was slightly better, and the projected rate of increase was slightly faster (Figures 17 a & b).

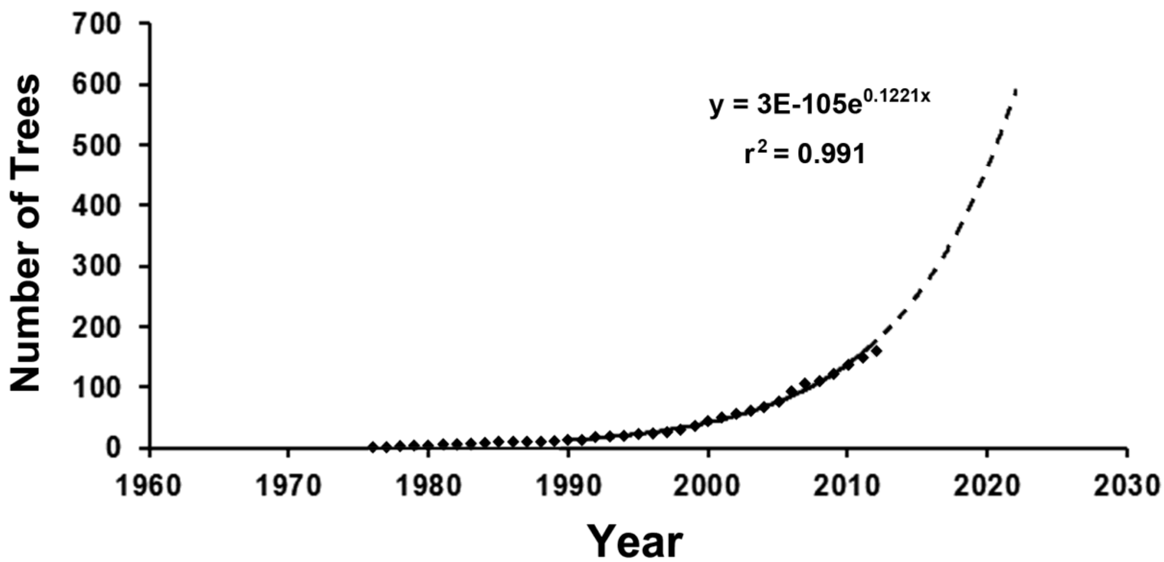

Figure 17a. Number of *I. aquifolium* trees ≥ 10 years old in St. Edward Park study area from beginning of invasion to 2012 (points), and projected to 2022 (dashed line). Exponential curve fit from 1990 to 2012 data has a doubling time of approximately six years and predicts that absent removal of trees in this study, more than 600 trees ≥ 10 years old would exist in the study area by 2022 (assuming negligible mortality of established trees; see Stokes et al. 2014).

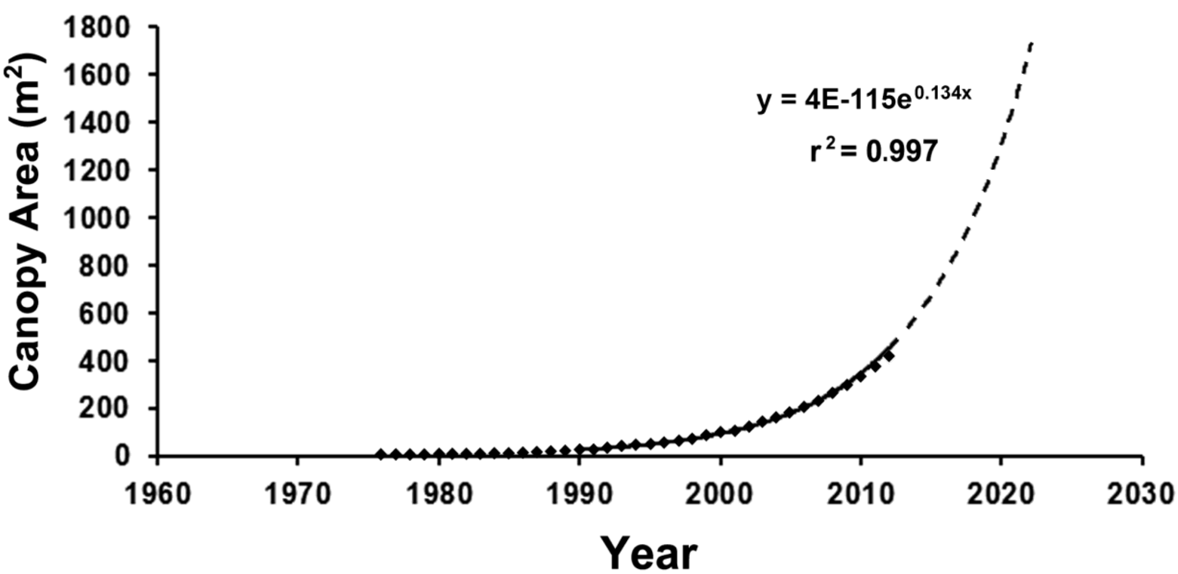

Figure 17b. Total % of study area covered by *I. aquifolium* canopy in St. Edward Park study area from beginning of invasion to 2012 (points), and projected to 2022 (dashed line). Exponential curve fit from 1990 to 2012 data has a doubling time of approximately 5 years. See Stokes et al. 2014.

Time spent on field work and estimated labor requirements for holly removal

In 2013, Fisk, Church, and Stokes spent a total of approximately 44 person-hours in the field locating, measuring, and removing holly. No chainsaw assistance was required. In 2012, Church, Cronkright, and Stokes spent a total of 89.5 person-hours in the field and State Parks employee John Delisio spent a total of approximately 1.5 hours chainsawing large holly trees that were located. In 2011, Campbell, Phillips, and Stokes spent a total of approximately 124 hours in the field and John Delisio spent approximately 2.5 hours chainsawing large holly. Thus, over the three years of the study, a total of 257.5 person hours plus 4 hours of chainsawing were spent accomplishing the field aspects of this project. On average, we estimate that 80% of our field time was spent on research-related activities, and 20% of the time was spent finding trees and removing them (i.e., the activities that would be part of an effort aimed purely at control of holly). Accordingly, we calculate that it took approximately 51.5 person-hours of labor plus 4.0 person hours of chainsawing to find and clear holly from 22.8 acres (9.2 hectares) of St. Edward parkland, or approximately 2.3 hrs per acre plus 0.18 hr chainsaw assistance per acre).

Based on our sample, if holly occurs at the same density throughout forested portions of St. Edward Park, and there are 296 forested acres in the park (M. Mostafavinassab *pers. comm.*), we calculate that removal of holly from the remaining 273 forested acres of the park (i.e., the area we have not treated) would require approximately 628 person hours (@ 2.3 hrs per acre) plus 49 hours (0.18 hrs per acre) of chainsaw assistance. This is a preliminary approximation that can be more reliably quantified with additional sampling, particularly in forest types not sampled in the current study. Effectiveness and permanence of different removal methods should also be determined to accurately assess resource needs for holly control over the long term. It should also be noted that because there is a low and quickly reached size threshold (~ 5 cm basal stem diameter) beyond which holly usually cannot be uprooted, the longer the invasion proceeds unchecked, the greater the numbers of holly which must be removed by the more labor-intensive methods of chainsawing and herbicide application.

Effectiveness of removal methods

To determine the effectiveness of our holly removal methods, in 2013 we re-visited sites where holly was removed during the 2011 and 2012 field seasons to look for evidence of holly survival. Field work was conducted by Ariel Williams and Abby Matthaeus under the direction of Dr. Stokes. Preliminary results (Appendix F) indicate that removal as practiced in this study prevented survival and re-sprouting of holly in slightly more than 50% of cases. Methods differed in their effectiveness; uprooting had a kill rate (i.e., no live sprouts were observed) of 59%, cutting at ground level had a kill rate of 21%, and cutting plus stump treatment with 18% glyphosate herbicide had a kill rate of 62%. In addition to being more likely to re-sprout, trees that were removed by cutting (only) produced greater numbers of sprouts and larger sprouts than trees removed by uprooting or cutting and herbiciding. Logistic regression analysis indicated that in addition to treatment method, size of tree and date of removal were significant predictors of removal success. Smaller trees and trees removed in winter were more likely to be successfully eradicated than larger trees and trees removed in spring. These results are preliminary, and we will be conducting further analysis in the coming year.

CONCLUSIONS

See Conclusion from Stokes et al. (2014), attached (Appendix A).

2013 Addendum:

Results from the 2013 field season do not change the overall conclusions of the study expressed in Stokes et al. The only addition to the conclusions based on the 2013 data is that the large number of small seed-established holly in a localized area within the 2013 sample area suggest that some areas of the park may be susceptible to high rates of seed-established holly, perhaps due to high propagule pressure near large holly seed sources on residential properties adjacent to the Park.

Management recommendations

See Management recommendations from Stokes et al. (2014), attached (Appendix A).

Further research needed

Additional data collection to increase the range of plant communities sampled

Additional field data will allow us to investigate questions such as whether some of St. Edward Park's forest types are more invaded than others (e.g., deciduous versus evergreen forest; see Appendix E) and whether some native plant communities and species are more negatively affected than others. We propose sampling an area of conifer-dominated forest (i.e., Douglas-fir-Western Hemlock forest (PSME-TSHE or TSHE-PSME Chappell 2006) in the park polygons 4, 5, 7, 11, 16, 21, or 22; Smith 2006). Doing this field work will also result in elimination of holly over an additional portion of the park's forest.

Spatial probability model of site vulnerability to holly invasion

Through analysis in a GIS of our existing spatial information and additional field data, we are using the 2011-2013 sample and study area to construct a spatially explicit invasion risk landscape model that may allow prediction of vulnerability to invasion by English holly. Factors such as current distribution, dispersion characteristics, and environmental variables can be integrated to produce a map of St. Edward Park showing likelihood of holly establishment. This model could be used to help decide where to focus holly search effort and removal activities. Ultimately, the model could be applied to other forested environments in the Pacific Northwest where holly invasion is a threat. We are currently surveying for holly in a different area of the park (polygon 19) with the same forest type (ALRU/POMU [Chappell]) as the 2011-2013 study area to allow for a test of the model.

Effectiveness of removal techniques

A critical need for management of English holly is to determine the effectiveness of various removal methods and their degree of permanence. We have taken a first step in this effort, by comparing removal effectiveness of pulling, cutting, and cutting with herbicide treatment of the stump (Appendix F). Additional questions that should be pursued are: What herbicide is most effective for controlling holly? Also, does stacking of removed holly result in new sprouting? And once controlled, how likely is re-invasion? We intend to look for new sprouts (establishment from seed) in new locations to evaluate propagule pressure and the continuing and future threat of invasion from seed.

Improvement of predictive population and cover models with more data

Additional sampling data and analysis of that data can produce a more robust model of holly population and canopy increase, both past and future. Specific topics needing more work include determination of actual holly mortality rates, which will be refined with a larger sample, and investigation of possible density dependent factors that could limit holly spread. An improved model will give a more accurate picture of the future threat posed by holly and the resources necessary for control.

Effects of holly on other species

Despite recognition of negative effects of English holly among land managers, the degree to which holly affects and excludes native species is not well known or documented. The observations of negative effects presented in Stokes et al. (2014) and in our previous reports (Stokes and Campbell 2011, Stokes et al. 2012) should be validated with larger samples. In addition, better understanding of the mechanisms of the negative effects is needed. We have collected data and plan further systematic sampling that will allow us to evaluate and better document the level of exclusion of other species by holly, and to draw conclusions about the nature of the mechanisms by which this exclusion occurs. Understanding these mechanisms may be useful in minimizing the effects of holly on native species. In addition to shade and leaf-litter, two other potential mechanisms, water competition and allelopathy, merit investigation. Holly's consumption of soil water may have a negative impact on other plants, particularly during dry periods such as those characteristic of summers in the Pacific Northwest. Allelopathy may also contribute to the dramatic decrease in native vegetation present underneath holly. Another invader of PNW forests, English ivy (*Hedera helix*), appears to alter soil chemistry in a way that negatively affects native vegetation (Heckman 2007).

Ecophysiology of holly

Better understanding of the physiological aspects of holly germination, growth, and spread is needed to understand its invasiveness and perhaps gain insights into potential means of control. Understanding the physiological function of holly clumps may also be important in this regard.

Effects of holly on riparian and in-stream habitats

Little is known about holly's effects on riparian habitat. In the context of biodiversity conservation and land management, this could be one of the most important dimensions of the holly invasion, as several federally listed salmonid species occur in areas where holly is invading. By occupying locations that would otherwise be sites of establishment for larger native tree species, holly may be degrading riparian and in-stream habitat for salmonids. Systematic investigation of the impacts of holly on riparian vegetation is needed.

ACKNOWLEDGEMENTS

We thank Washington State Parks and the staff of St. Edward State Park for their considerable assistance with this project. We also thank Elliott Church for help with the field work. This research relied heavily on field work by undergraduates, which was made possible through a grant from the University of Washington Bothell Office of Research to support undergraduate participation in research.

LITERATURE CITED

See Literature cited from Stokes et al. (2014), attached (Appendix A).

2013 Addendum:
References included in this report:

Chappell, C.B. 2006. Upland plant associations of the Puget Trough ecoregion, Washington. Natural Heritage Rep. 2006-01. Washington Department of Natural Resources, Natural Heritage Program, Olympia , Wash. [http://www1.dnr.wa.gov/nhp/refdesk/communities/pdf/intro.pdf].

Heckman A. 2007. Soil Properties Associated with English Ivy (Hedera spp) Infestations in Pacific Northwest Urban Forests [Master's Thesis]. Seattle (WA): University of Washington.

Peterken, G. F., and P. S. Lloyd. 1967. Biological flora of the British Isles: *Ilex aquifolium* L. Journal of Ecology 55:841-858.

Richards, A. J. 1988. Male predominant sex ratios in Holly *(Ilex aquifolium* L., Aquifoliaceae) and Roseroot *(Rhodiola rosea* L., Crassulaceae). Watsonia 17:53-57.

Smith, H. 2006. Rare Plant and Vegetation Survey of Saint Edward State Park. Report to Washington State Parks. Pacific Biodiversity Institute, Winthrop, WA.

Stokes, D.L., and C. Campbell. 2011. Invasion of English Holly (*Ilex aquifolium*) at St. Edward State Park. Report to Washington State Parks, 26 pp.

Stokes, D.L., Church, E.D., Cronkright, D.M., and S. Lopez. 2014. Pictures of an invasion: English Holly (*Ilex aquifolium*) invasion of a Pacific Northwest forest. *Northwest Science, vol. 88*.

Stokes, D.L., Cronkright, D., Church, E., and S. Lopez. 2012. English Holly (*Ilex aquifolium*) Invasion in Saint Edward State Park. Report to Washington State Parks, 35 pp.

May 5, 2014: Stokes, Fisk, & Lopez; English Holly in St. Edward Park

APPENDIX A (Attached)

Stokes, D.L., Church, E.D., Cronkright, D.M., and S. Lopez. 2014. Pictures of an invasion: English Holly (*Ilex aquifolium*) invasion of a Pacific Northwest forest. *Northwest Science*, vol. 88:75-93.

APPENDIX B

Field personnel:

2011:
David Stokes, Associate Professor, University of Washington, Bothell

Caitlin Campbell, undergraduate senior, University of Washington, Bothell
now: BSc Environmental Science 2011

Rachel Phillips, undergraduate senior, University of Washington, Bothell
now: BA Environmental Studies 2011

2012:
David Stokes

Elliott Church, undergraduate senior, University of Washington, Bothell
now: BSc Environmental Science 2012,
and Master of Science student, UW School of Environment and Forest Sciences

David Cronkright, undergraduate senior, University of Washington, Bothell
now: BSc Environmental Science 2012

2013:
David Stokes

Katrina Fisk, undergraduate senior, University of Washington, Bothell
now: BSc Environmental Science 2013

Joanna Mead (Appendix E), undergraduate senior, University of Washington, Bothell
now: BA Environmental Studies 2013

Abby Matteus (Appendix F), undergraduate senior, University of Washington, Bothell
now: BSc Biology 2013

Ariel Williams (Appendix F), undergraduate senior, University of Washington, Bothell
now: BA Environmental Studies 2013

APPENDIX C

Data collected:

For each sampled holly tree we recorded:
- Tree ID number
- Geographic location (lat, lon) if located with GPS
- Bearing and distance (m) from GPS location if < 20 m of GPS location
- Diameter at base (cm)
- Diameter at 20 cm above ground (cm)
- Diameter at breast height (cm)
- Tree height (m) (or length of central stem if prostrate)
- Crown diameter (m)
- Foliage density (light, med, dense)
- Presence/absence of berries (Y/N)
- Apparent source (vegetative spread, spread from seed, unknown) (2012 & 2013 only)
- Removal method (pull, cut with herbicide, cut without herbicide)
- Comments (connections to other trees, evidence of prior cutting, damage, numbers of small holly plants within 1 m, presence of relay trees)

At each clump (group) of holly trees we recorded the following environmental data:
- Tree ID number
- Slope
- Aspect
- Distance from stream/trail (m)
- East-West canopy type (Deciduous, Evergreen)
- East-West canopy density (%)
- Canopy tree species
- Canopy tree species within 5 m of holly tree
- Shrubs within 5 m of holly tree (% area covered by species)
- Ground cover within 5 m of holly tree (% area covered by species and % bare)
- Ground cover species under holly and % bare)

Lab work consisted of examination of cross-sections with hand lens and dissecting scope to count of number of annual rings.

APPENDIX D

Native plant species found in ground cover or shrub layer within a 5 m radius of holly clumps (n = 33 sites) in study area, listed in order of frequency of occurrence:

Species	Common Name	Number of sites
Rubus ursinus	Native blackberry	32
Polystichum munitum	Sword fern	30
Mahonia nervosa	Dwarf Oregon grape	20
R. spectabilis	Salmonberry	18
Vaccinium parvifolium	Red huckleberry	13
Sambucus racemosa	Red elderberry	13
Gaultheria shallon	Salal	11
Athyrium filix-femina	Lady fern	9
Thuja plicata	Western red cedar	7
Oemleria cerasiformis	Indian plum	5
Corylus cornuta	California hazelnut)	4
Urtica dioica	Stinging nettle	3
Rosa spp.	Rose	2
Acer macrophyllum	Bigleaf maple	1
Tiarella trifoliata	Threeleaf foamflower	1
Trillium ovatum	Pacific trillium	1

Appendix E (Attached)

Fisk, K. and Mead, J. 2013. Forest Type, Canopy Coverage and Occurrence of *Ilex Aquifolium* within Saint Edward State Park, Kenmore, Washington (USA). Undergraduate research paper, under direction of Drs. Stokes and Lopez. Results preliminary; further analysis in progress.

Appendix F (Attached)

Williams, A., and A. Matthaeus. 2013. The Effectiveness of Common Removal Methods for the Eradication of English Holly (*Ilex aquifolium*). Undergraduate research paper, under direction of Dr. Stokes. Results preliminary; further analysis in progress.