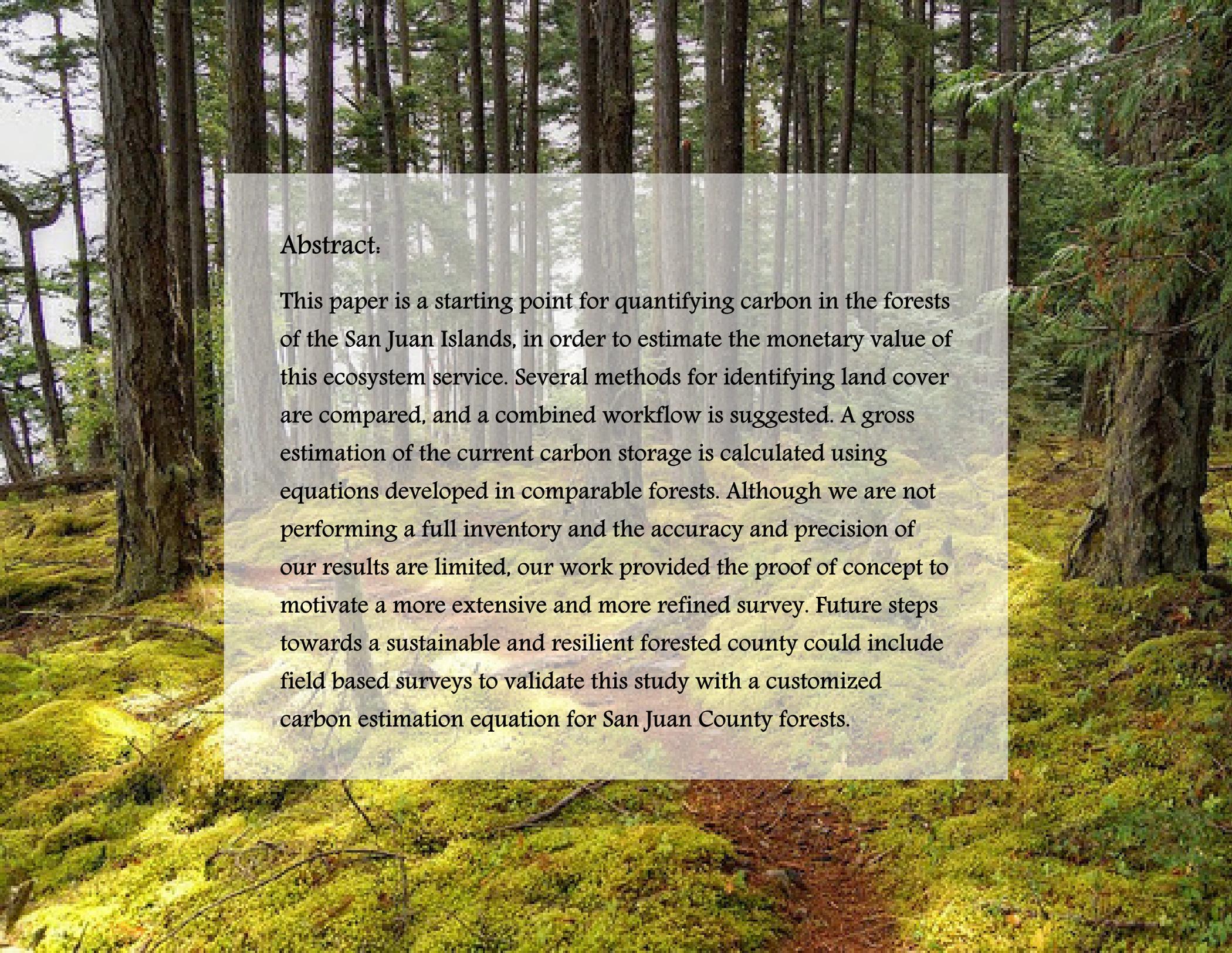


A scenic view of a forested coastline. In the foreground, a large, young evergreen tree stands prominently on the left. The middle ground shows a dense forest of evergreens along a shoreline. In the background, a large body of water (a bay or fjord) is visible, with several small boats anchored. The sky is blue with light, wispy clouds. The overall scene is bright and clear, suggesting a sunny day.

# Remote Sensing Carbon in Douglas Fir Forests of San Juan Island

By Nathan Teut and Bethy Johnstonbaugh

The background of the slide is a photograph of a forest. The trees are tall and thin, with a dense canopy. The forest floor is covered in a thick layer of green moss and fallen leaves. The lighting is soft, suggesting a misty or overcast day.

## Abstract:

This paper is a starting point for quantifying carbon in the forests of the San Juan Islands, in order to estimate the monetary value of this ecosystem service. Several methods for identifying land cover are compared, and a combined workflow is suggested. A gross estimation of the current carbon storage is calculated using equations developed in comparable forests. Although we are not performing a full inventory and the accuracy and precision of our results are limited, our work provided the proof of concept to motivate a more extensive and more refined survey. Future steps towards a sustainable and resilient forested county could include field based surveys to validate this study with a customized carbon estimation equation for San Juan County forests.

## Introduction.

This preliminary remote sensing study of the ecosystem services provided by the forests of San Juan Island, WA is presented by University of Washington graduate students in collaboration with Kwiaht, Center for the Historical Ecology of the Salish Sea. Only eight weeks were allocated to creating a simple “proof of concept” that can be used to support a more detailed and more extensive study of how these forests affect the carbon cycle. There are two components to this study: a survey of available remote sensing methods and data, and a measurement of ecosystem services.

Healthy forested lands provide intangible benefits to people in and near them. These natural assets are commonly referred to as “ecosystem services.” More specifically, ecosystem services are commonly defined as “benefits people obtain from ecosystems” (Ecosystem Services, 2013). This includes carbon storage and sequestration, stormwater runoff mitigation, decreases in erosion pressures, decreases in sedimentation rates, increased biodiversity, energy savings, and increased aesthetic beauty in urban environments (Urban Forest, 2012; Ecosystem Services, 2013). These services are traditionally viewed as natural benefits and a part of the public good. Since they commonly lack formal markets, there is con-

siderable difficulty in assessing monetary values for ecosystem services, and they are commonly left out of policy decision making processes (Ecosystem Services, 2013).

Although the global carbon cycle and its participation in the virtually all social ecological systems is out of scope for this study, San Juan County, like many localized regions, can participate in mitigating climate change by sustainably maintaining adequate forest cover across all islands that will sequester and store the carbon produced by an increasing human population. Climate change is widely accepted by the scientific community as a human caused problem primarily from the burning of fossil fuels and releasing carbon in the form of carbon dioxide (CO<sub>2</sub>) into the atmosphere. Global deforestation contributes to the problem by removing the sink that tree biomass provides for removing carbon from the atmosphere. The pursuit of carbon neutrality or carbon sequestration surplus is seen a main tactic for combating climate change.

The attainability of this carbon neutrality goal is dependent of being able to quantify forest cover as well as estimates of carbon sequestration and storage provided by this forest cover. This information can be used to determine forest management plans that will likely differ from those that are in place in the county already. At-

tempting to use remote sensing techniques to attain these estimates of forests and their carbon mitigating ecosystem service is a logical first step and is the scope of this study.

The most common forest types on San Juan Island are characterized by the co-occurrence of Douglas Fir (*Psuedotsuga menziesii*) with other tree species such as Grand Fir (*Abies grandis*) and Western Red Cedar (*Thuja plicata*) or with undergrowth species such as Salal (*Gaultheria shallon*) and Ocean Spray (*Holodiscus discolor*). Pacific Madrone (*Arbutus menziesii*) which grows on steep, sunny, shorelines, and Red Alder (*Alnus rubra*) which grows in low-lying, wet, woodlands, are exceptions to the coniferous pattern. Sequestering carbon is the most important ecosystem service that Douglas Fir forests provide. Wet woodlands provide better habitat for supporting animal biodiversity, but Douglas Fir forests provide the largest terrestrial carbon sink. Both forest types help regulate runoff and erosion. (Chappell, 2006)

Douglas Fir trees are the only organisms sequestering significant carbon on San Juan Island. Peat bogs and juniper trees (*Juniperus scopulorum*) are notable carbon sink because they store carbon for a long time without releasing it back into the atmosphere, but peat bogs cover less than 1% of San Juan County and juniper trees grow

only on undisturbed shoreline. Given a growing human population on the islands of San Juan County, put very simply, the sustainability of the carbon cycle depends on growing enough Douglas Fir trees to compensate for the growing number of cars. An extensive carbon footprint study to determine any forest coverage threshold for carbon neutrality would also aid the county in long term carbon neutrality goals. However, San Juan County has ignored this ecosystem service.

In fact, tax incentives are still available for cutting down Douglas Fir trees. Designated Forest Land receives the largest tax break available in San Juan County, and the stated goal of the program is to encourage “maximum timber production.” The program defers property tax revenues until a later date when forests are harvested. Not all land-owners with “Designated Forest Land” are interested in harvesting timber, and some are even opposed to it. But enrollment in the program requires filing and following a 30-year timber management plan dictating future forest harvesting that is increasingly being enforced by the County.

The design of this taxation program suits the historical importance of the logging industry. Extensive cutting for timber and industrial fuel continued until the old-growth forest virtually vanished by the 1940s.

Island forests were commercially convenient, because logs could be rolled down to the beach and floated away. Despite the tax incentives, harvest yields have steadily dropped. Some previously logged land appears to have regrown, but forest productivity is low and the forests have not had time to mature. The current rate of harvest is depleting the forest. (Schroeder)

Due to the historical logging, the remaining forests of the San Juan Islands strongly resemble commercially managed timber stands. Nearly 70% of the trees are a single species, Douglas Fir. Most of the individual trees are between 50 and 75 years old (Schroeder). As the forest matures, the canopy will close and tree growth will slow. The most rapid acceleration of carbon sequestration takes place before that happens, although the rate continually increases as trees grow. The taxation system could be restructured to value the Douglas Fir forests' ability to provide ecosystem services like removing carbon from the atmosphere.

The extensive Seattle Ecosystem Values report provides a nearby example of policy driven by ecosystem services assessment. It estimates that the City of Seattle's urban forests cover roughly 23% of the city across all regions, while providing a carbon storage capacity of 2 million metric tons (or 2.2 million short tons) (Ciecko,

2012). Seattle's long term Urban Forest Management Plan advocates a goal of increasing the canopy coverage from 23% to 30% by 2037 in order to increase the value of this storage capacity as well as realize more benefits in terms of stormwater runoff mitigation, energy savings, and increasing the aesthetic quality of all regions and neighborhoods (Urban Forest, 2012).

Seattle's assessment and goals rely on a heavy hands-on data collection effort, coupled with using i-Tree Eco as the data analysis software. Eco requires a boots-on-the-ground bottom-up approach to get an actual inventory of individual species and metrics of individual trees like height and diameter at breast height. In contrast, our study is centered on the top-down approach, where we look at remote sensing techniques to quantify the forest on the islands as best as possible (Nowak). This is cheaper and faster approach so long as data is available, however, disadvantages include needing access to some specific software (like ArcMap, SPRING, or Fusion) and the possible falsehoods and errors generated by inaccuracies in the remote sensing data or processing techniques (Nowak).

A freeware application called SPRING categorizes a land cover raster from orthophotos. The user creates classification rules from the bottom up, by manually

classifying a large sample of pixels. A land cover raster is crucial to remote sensing ecosystem services and nothing appropriate to this study is readily available, so SPRING is an important part of the workflow. An extremely well written, at length step by step guide was published by Moskal et al. in 2011 (Moskal, 2011). This English language resource is especially valuable because SPRING is a product of the Brazilian government, and therefore most of the technical support information is written in Portuguese.

I-Tree is a suite of freeware applications that output maps and tables measuring ecosystem services based on specific data resources. Using the software is relatively easy, and the methods are well documented. A broad range of ecosystem services can be surveyed, but the tools vary in the data input needs. Some applications rely on hands-on site specific species inventories and metric measurement surveys (i-Tree Eco and Streets), while others use on-line data resources like the National Land Cover Database and Google Maps (i-Tree Vue and Canopy) along with national average calculated forest metrics to estimate ecosystem services. The i-Tree outputs can be used to calibrate other methods that have greater applicability.

Another freeware application called FUSION

transforms raw LiDAR point cloud data into DEMs and other surfaces. Although it is a powerful application, the user interface is somewhat confusing at first, and the data processing capabilities are difficult to understand. The user can execute great control on the outputs and metrics. However, commercially produced DEMs are sufficient for this preliminary study, so customizing the LiDAR surface isn't an important part of the workflow.

ArcMap ModelBuilder has the capability to link tools and pull together the land cover raster and the LiDAR DEMs (Fig 1). A new toolbox automating all of the the ArcMap methods used in this study makes it much easier to repeat the methods used in this study, and ModelBuilder diagrams present the workflow in a format familiar to many GIS analysts.

At the Twelfth Biennial USDA Forest Service Remote Sensing Applications Conference in 2008, Jim Muckenhoupt presented a very clever method for delineating individual trees from a LiDAR DEM. They flipped a vegetation height raster upside down, and then analyzed it with ArcMap hydrology tools. Each treetop in the canopy of the forest becomes a drain, or sink, and the depth of the sink equals the height of the tree. (Muckenhoupt, 2008). Some of the resulting peaks are actually rooftops, not trees, but many of those false posi-

tives can be eliminated by comparison with land cover data. Basins are delineated from sinks and used in turn to calculate percent forest cover. ArcMap's raster calculator is also the best tool for calculating allometric carbon analysis.

A quick test-run only scratches the surface of a GIS software application's capabilities. Years of experience with ArcMap provide useful familiarity with the user interface, but do not make one an expert at every tool. The freeware applications tested in this study have narrower scope, but also have limited technical support and plenty of quirks. In this study we attempted to judge the accessibility of each program against the value of the results it produces. However, the software guidance in this study is based on our own opinions, formed in the midst of the steep beginning of the learning curve.

Allometric analysis is based on the mathematical relationship between carbon density and the size of the trees. Extensive research in the amazon rainforest and other tropical areas shows carbon density has a parabolic relationship to mean canopy height, basal area, and wood density (Asner 2009). The exact relationship varies by region and forest type, so the equation must be calibrated.

Lefsky modeled carbon density at 112 temperate deciduous, 21 temperate coniferous and 16 boreal conif-

erous plots. Their general regression equation:

AboveGroundBiomass =

$$0.342 * (\text{MeanCanopyHeight})^2 + 2.086 * (\text{MeanCover} * \text{MeanCanopyHeight})$$

is reported to explain 87% of the variance at the temperate coniferous plots and 84% of the variance at all plots. Although the forests in our study are temperate and coniferous, they grow in a drier climate with poorer soil than the Western Oregon forests studied by Lefsky. As mentioned earlier, the forests on San Juan Island are also very homogeneous and immature. However, until Kwiaht is able to perform their own field calibration, Lefsky's model seems to be the best available. (Lefsky 2002)

This study is only a starting point for quantifying carbon in the forests of the San Juan Islands. Currently, LiDAR and orthophotos of San Juan Island are only updated once or twice in a decade, so they provide a snapshot in time, not long-term monitoring. The low precision of this preliminary study would also be problematic for long term monitoring, because small changes over time could be lost in the noise. However, a reliable baseline will be useful as new methods and data sources, such as satellite hyper-spectral imagery, make

regular monitoring feasible.

Even a rough approximation supports the argument in favor of measuring ecosystem services. Hopefully this “proof of concept” will be used to justify and procure funding for Kwiaht to perform a six to eight week study employing two GIS analysts, two field biologists, and one intern, full time. The workflow of this future study would be guided by our preliminary survey of the available software. Kwiaht operates very frugally using a business model copied from small research stations in third-world countries, so our focus on freeware and free data suits them. They also often train volunteers from the local community, so many of the time-intensive data processing tasks (e.g. “training” SPRING and i-Tree) could be shared. Having a trained botanist ground-truth the land cover raster and calibrate the allometric regressions would greatly improve the reliability of the results.



## Materials and Methods.

For a more detailed description of the pitfalls and successes of our software exploration, see Appendix A.

### *Machine.*

All processing was carried out on a 2.8 Ghz Intel Dual Core; 8G RAM laptop.

### *Study Area.*

San Juan Island (SJI) shoreline was extracted from the San Juan County shorelines published by NOAA in 2011 and used to extract all rasters and images. The area of San Juan Island (143 km<sup>2</sup>) was near the limit of reasonable data processing time, although methods described below can be applied to other areas of interest inside or outside San Juan County. The processing requirements for this type of analysis can be very high, even if only looking at San Juan Island, as is the scope for this report.

### *SPRING.*

A high resolution (1m) aerial photography mosaic of San Juan County (2.24 GB) in 2011 was provided by the National Agriculture Imagery Program. The projection for this data was NAD83 UTM Zone 10N. Only 3 spectral bands were obtained, because the near-

infrared band was not available online, for free online but could be purchased. Using ArcMap, the data were clipped to the SJI shoreline, and exported as a georeferenced \*.tif file (0.3 GB). SPRING 5.2.3 (32-bit version) is Object Based Image Analysis (OBIA) freeware program designed by the Brazil National Institute for Space Research.

In SPRING, the project's projection and bounding box were manually entered before the image was imported. The segmentation window's bounding box was adjusted to divide the north end of the island from the south end, in order to limit the file size. The north and south ends of the island were separately segmented according to empirically derived parameters (similarity = 30, area = 40) which correctly identified easily recognizable features like tree stands, roads, buildings, pastures and parking lots. Segmented features were classified into three land cover types: Forest, Grassy/Non-Forest, and Urban/Impervious surface. Several million pixels were assigned to the classifications in order to "train" SPRING. The classification type was set to "Bhattacharya" and the acceptance threshold was set to "99.9." The resulting classifications were mosaicked together and exported as a \*.tif georeferenced image.

### *i-Tree Vue:*

Low resolution (30m) representations of land cover type, forest canopy cover (%), and impervious surface (%) were obtained from the National Land Cover Database through the Multi-Resolution Land Characteristics Consortium. The land cover and impervious surface data were collected in 2006, but the most recent forest canopy data available were collected in 2001. The datasets were clipped to the SJI shoreline in ArcMap and reprojected to the Nad83 HARN Washington State Planes North FIPS 4601 projection.

. I-tree Vue 5.0 is another freeware application designed by the USDA Forest Service.

In i-Tree Vue, these datasets were analyzed to estimate ecosystem services including carbon storage and sequestration, as well as the potential removal of carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, and fine particulate matter (<10 $\mu$ m) from the air. The option to correct for a small systematic underestimation of forest canopy and impervious surface in the National Land Cover Database was utilized. Simple models were also run to estimate the change in ecosystem services if the forest canopy were decreased to 50% coverage or increased to 65% coverage.

### *FUSION:*

Raw LiDAR point cloud data of San Juan County in 2009 was provided by the San Juan County GIS department and attempts were made to derive surfaces in FUSION 3.30, a freeware application designed by the USDA Forest Service's Pacific Northwest Research Station. These attempts were not successful, although tutorials run on sample data were successful. For this analysis, large amounts of time learning to use FUSION were deemed unnecessary since commercially produced DEMs were available.

### *ArcMap:*

High resolution (3ft) bare earth and top hit DEMs of San Juan County in 2009 (5.4 GB), processed by Watershed Sciences, Inc., were provided by the Puget Sound LiDAR Consortium. The projection for this data is the Nad83 HARN Washington State Planes North FIPS 4601. An educational trial version of Esri ArcInfo 10.1 for desktops, Service Pack 1, was used throughout this analysis.

The bare earth DEM was subtracted from the top hit DEM to yield a raster representation of vegetation height. The vegetation height raster was inverted and then the Flow direction and Basin tools were used to

delineate trees (>15ft). The Raster to Polygon and Feature to Point tools were used represent the trees as vector polygons and their centroid points. Trees located in Urban/Impervious Surface areas of the reprojected land cover image derived from SPRING were removed as false positives. Trees were assigned a height field from the value of the vegetation raster cell at their centroid. Rasters (1 acre resolution) representing average tree height and tree density were created using the Point to Raster tool.

Forest canopy coverage was independently calculated from the treetop points and the vegetation height raster. The overlap between the treetop polygons and the raster (1 acre resolution) was calculated by transforming each cell into a polygon and using the Intersect and Dissolve tools. Then the polygons were transformed back into a forest canopy raster using the Polygon to Raster tool. High-value (>15 ft) cells in the vegetation height raster were summed using the Aggregate tool to create a second forest canopy raster (1 acre resolution).

The forest canopy rasters and the average tree height raster were input to Lefsky's above ground biomass equation using the Raster Calculator.

ModelBuilder was used to link tools and automate the data processing described above. Each model was extensively tested for accuracy and smooth execution at several scales, beginning with small areas and ending with the whole area of San Juan Island.



## Results and Discussion:

### *SPRING:*

Spring produced a land cover raster with three classes: Forested (66.69%), Non-forested (29.79%), and Urban/ Impervious Surface (3.47%) (Fig 1). A few pixels were not classified (0.05%) due to programmatic error.

Visual inspection of a small area (Fig 2) shows that the segmentation step distinguished all features visible to the naked eye and more. However, the classification of these features is not perfect. For example, the small pond in the upper left quadrant is incorrectly classified as “Forested” because it is dark green. Manually classifying more pixels to “train” the program should improve the raster.

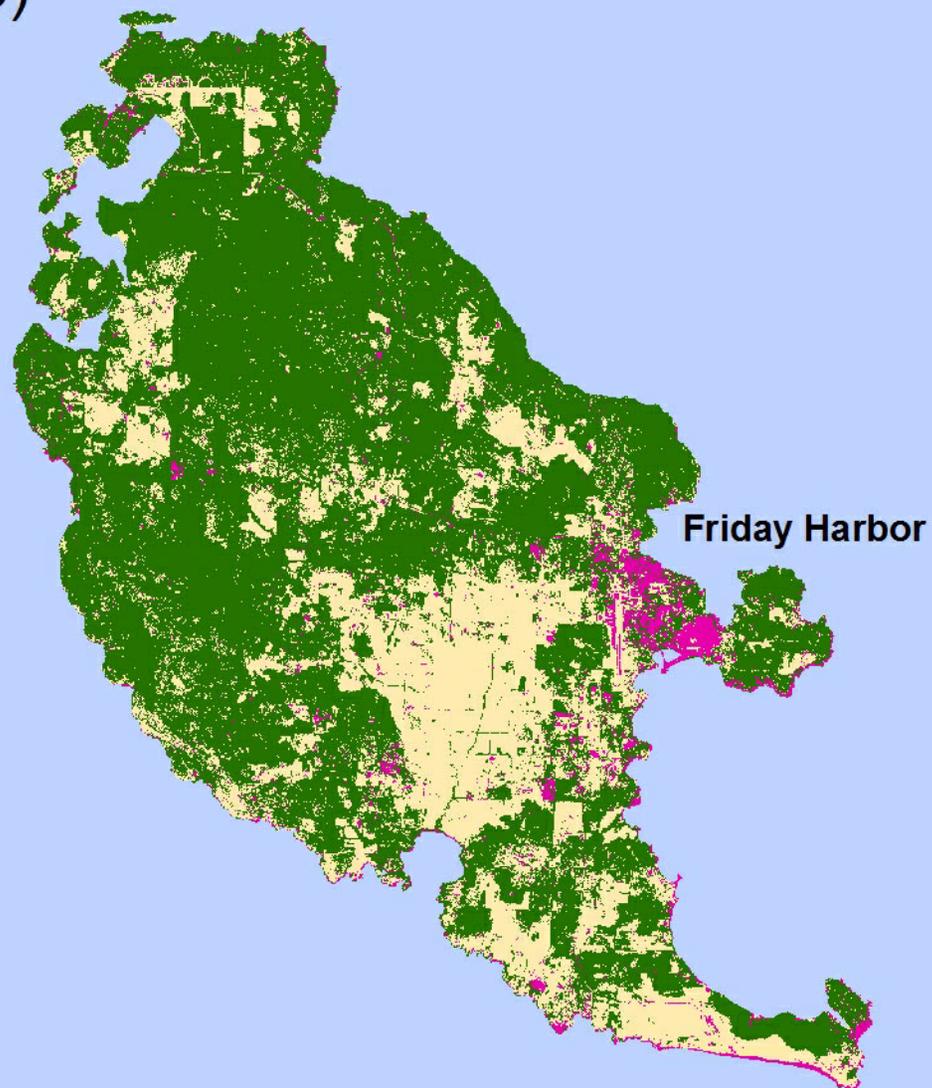
The Urban/Impervious Surface class is the most important to this preliminary study, because it is used to distinguish rooftops from treetops later in the workflow. SPRING’s segmentation process is easier and more sensitive than the manual digitization that San Juan County currently uses to locate impervious surfaces.

Although it is a touchy program overall and has trouble processing large image, we recommend including SPRING in future workflows (Fig 3). Perhaps a volunteer fluent in Portuguese could be recruited to translate technical support information if necessary. The land cover raster resulting from this preliminary study could be recreated with more accurate classification, especially if volunteers helped “train” SPRING. Kwiaht could also use SPRING to remote sense a more complicated land cover raster for the benefit of their other ongoing projects, such as mapping habitat types on all public lands in San Juan County.

a)

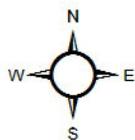


b)



0 1.25 2.5 5  
Miles

Bethy Johnstonbaugh & Nathan Teut; University of Washington  
Data Sources: National Aerial Imagery Program, USDA



### San Juan Island SPRING classes

- Forested
- not Forested
- Urban (impervious surfaces)

Figure 1. SPRING land cover classification: a) orthophotography input, b) land cover raster output.

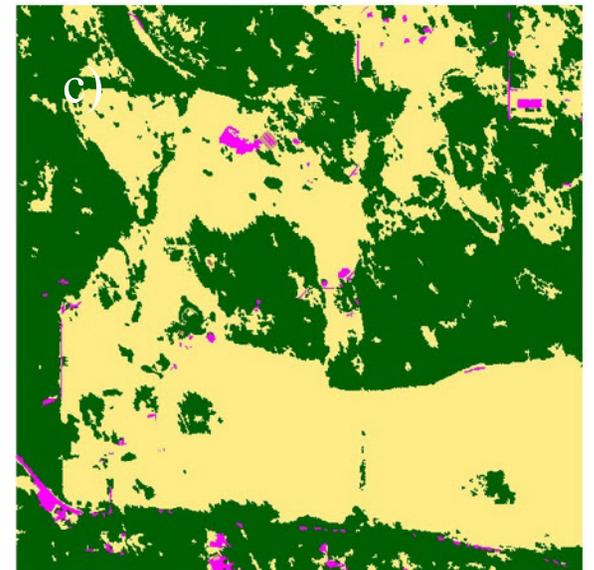
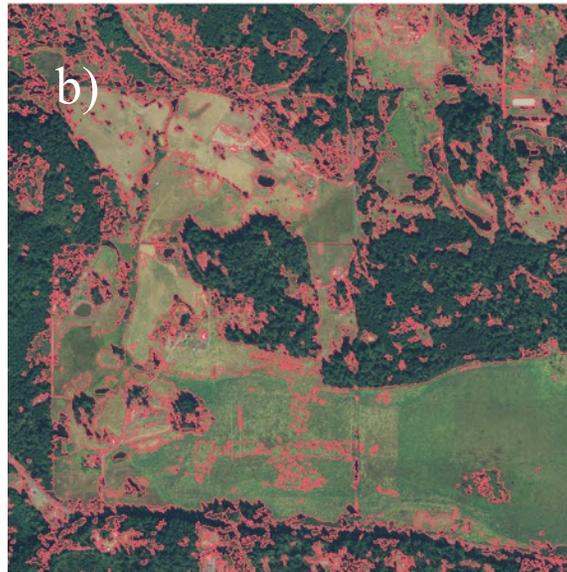


Figure 2: SPRING land cover segmentation and classification. a) orthophotography input, b) segmentation step, c) land cover raster output.

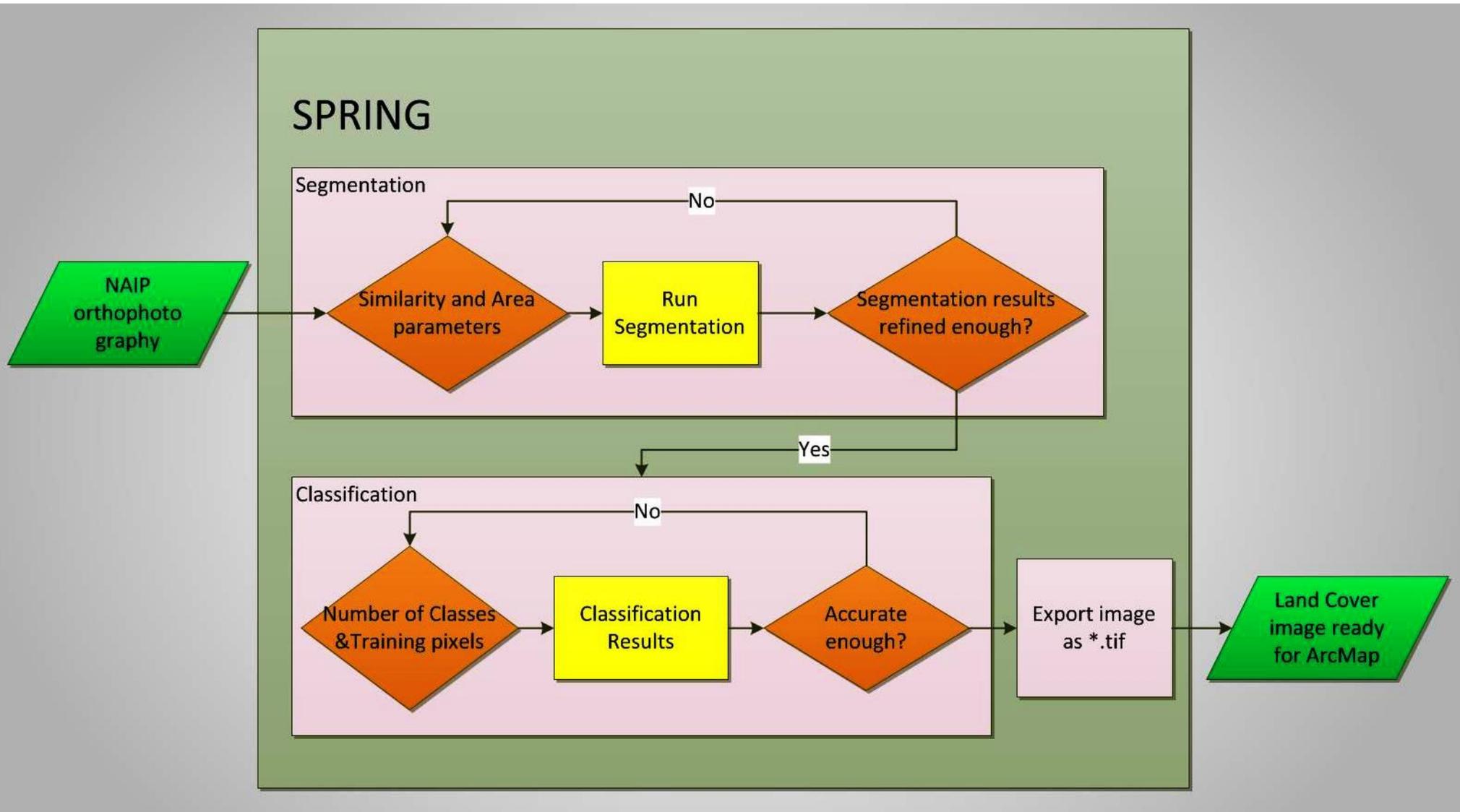


Figure 3. SPRING workflow diagram.

### *i-Tree Vue.*

The maps output by i-Tree Vue show the expected geographic patterns. Impervious surface is most abundant in the town of Friday Harbor and forest is more abundant on the north end of the island (Fig 4). The greatest delivery of ecosystem services such as carbon storage, carbon sequestration, and air pollution removal happens in the same forested areas (Fig 5).

I-Tree reports more impervious surface (4.5%) and less forest (58.1%) than the land cover raster output by SPRING. I-Tree analyzed data from 2001 and 2006, while SPRING analyzed data from 2011, so we would expect to see more developed land in the SPRING analysis. The difference probably appears because the data analyzed by i-Tree had lower resolution, and were classified without the benefit of local knowledge. I-Tree Vue also creates scenarios with varying forest canopy cover (Fig 6). The scenario of increased forest canopy cover could be used to account for the disparity.

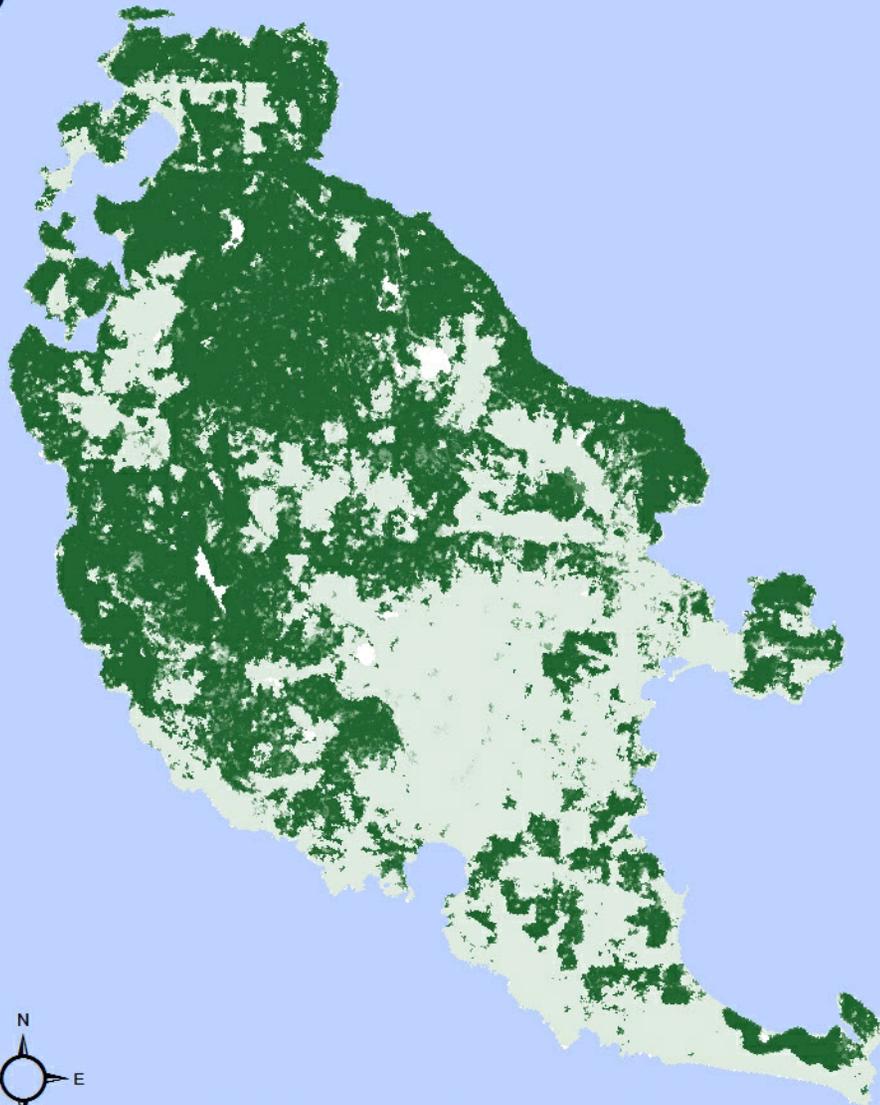
The strength of i-Tree lies in the sophistication of the ecosystem classifications. A more intensive study could duplicate these land cover classifications using SPRING. But comparing the mass of carbon storage and

sequestration delivered by each forest type confirms that evergreen forests are the most common forest type and the most important carbon sink on San Juan Island (Table 1). So perhaps the other forest types do not need to be included in this study.

According to i-Tree, the forests of San Juan Island provide \$1.5 million worth of carbon sequestration each year, and 47.7 million worth of carbon storage. The evergreen forests alone provide \$1.4 million worth of carbon sequestration each year, and \$42.5 million worth of carbon storage. Even accounting for a wide margin of error, these large numbers reflect the monetary value of not cutting down trees.

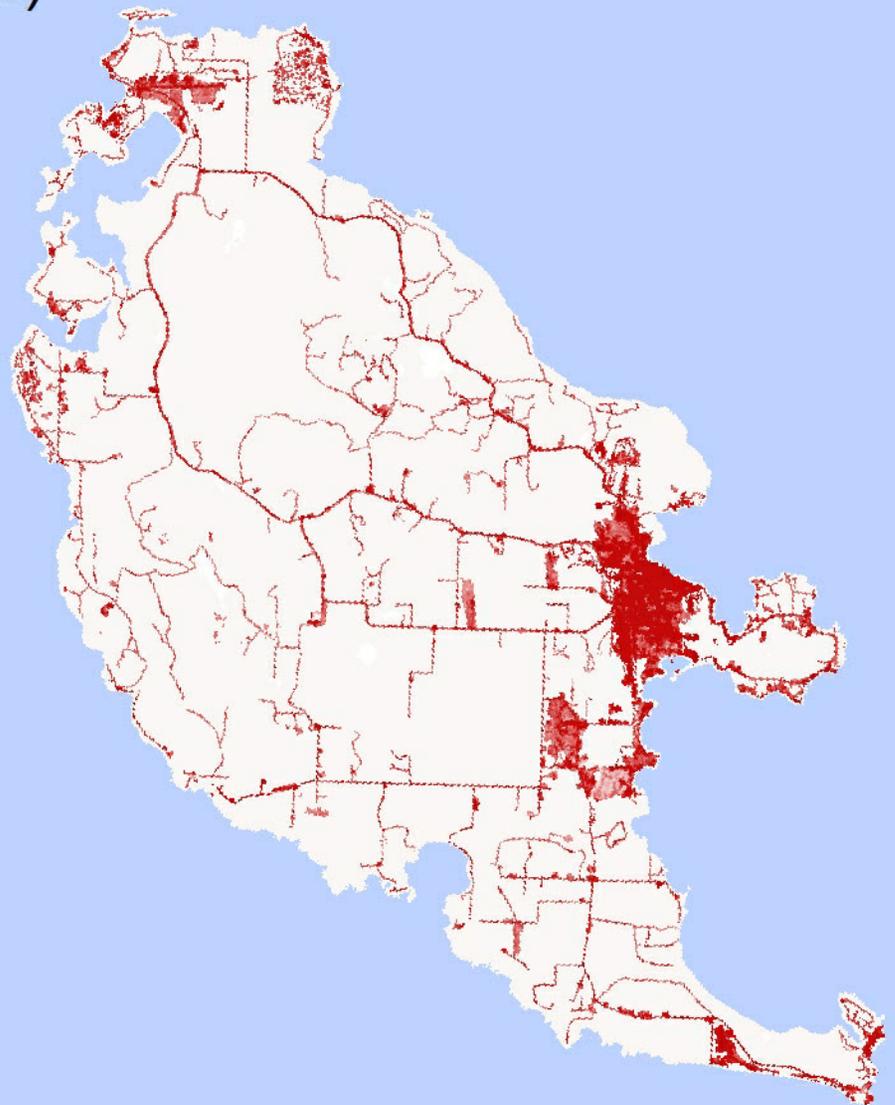
We recommend comparing the outputs of i-Tree to the outputs of other analysis methods. The i-Tree workflow (Fig 7) parallels the other analyses, but uses completely different data sources and calculations. Therefore it provides a useful data point against which other more customized methods can be checked.

a)



Total Forest Canopy: 58.1%

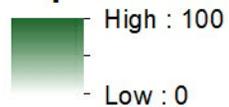
b)



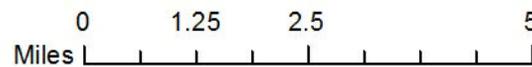
Total Impervious Surface: 4.5%

**Forest canopy coverage**

**% per 1 m cell**



**i-Tree Vue Outputs**



**Impervious surfaces**

**% per 1 m cell**



Bethy Johnstonbaugh & Nathan Teut; University of Washington Data Sources: National Land Cover Database

Figure 4. I-Tree Vue land cover classifications: a) forest canopy coverage, b) impervious surfaces coverage

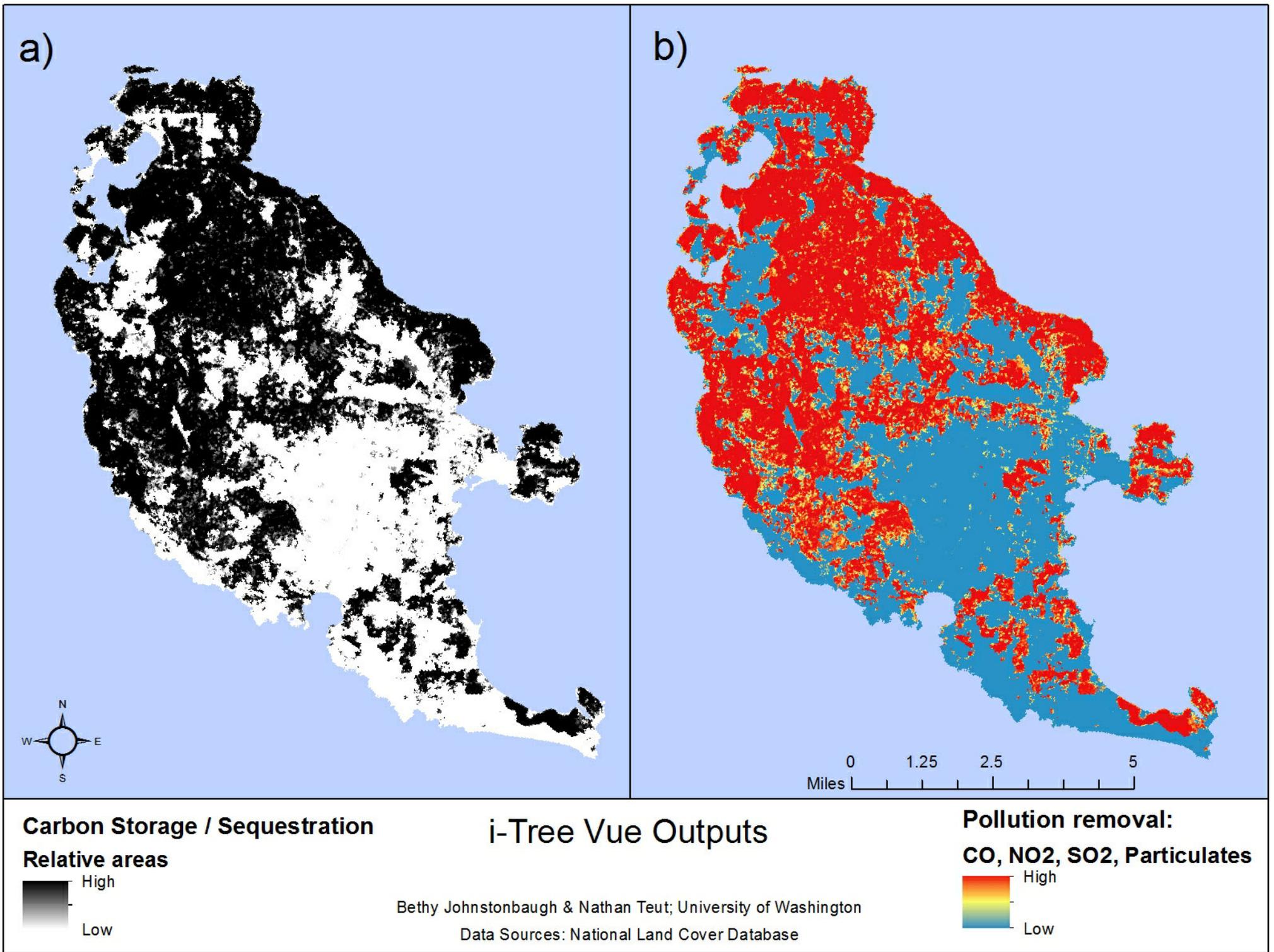


Figure 5: I-Tree Vue forest ecosystem services output a) carbon storage and sequestration b) pollution removal.

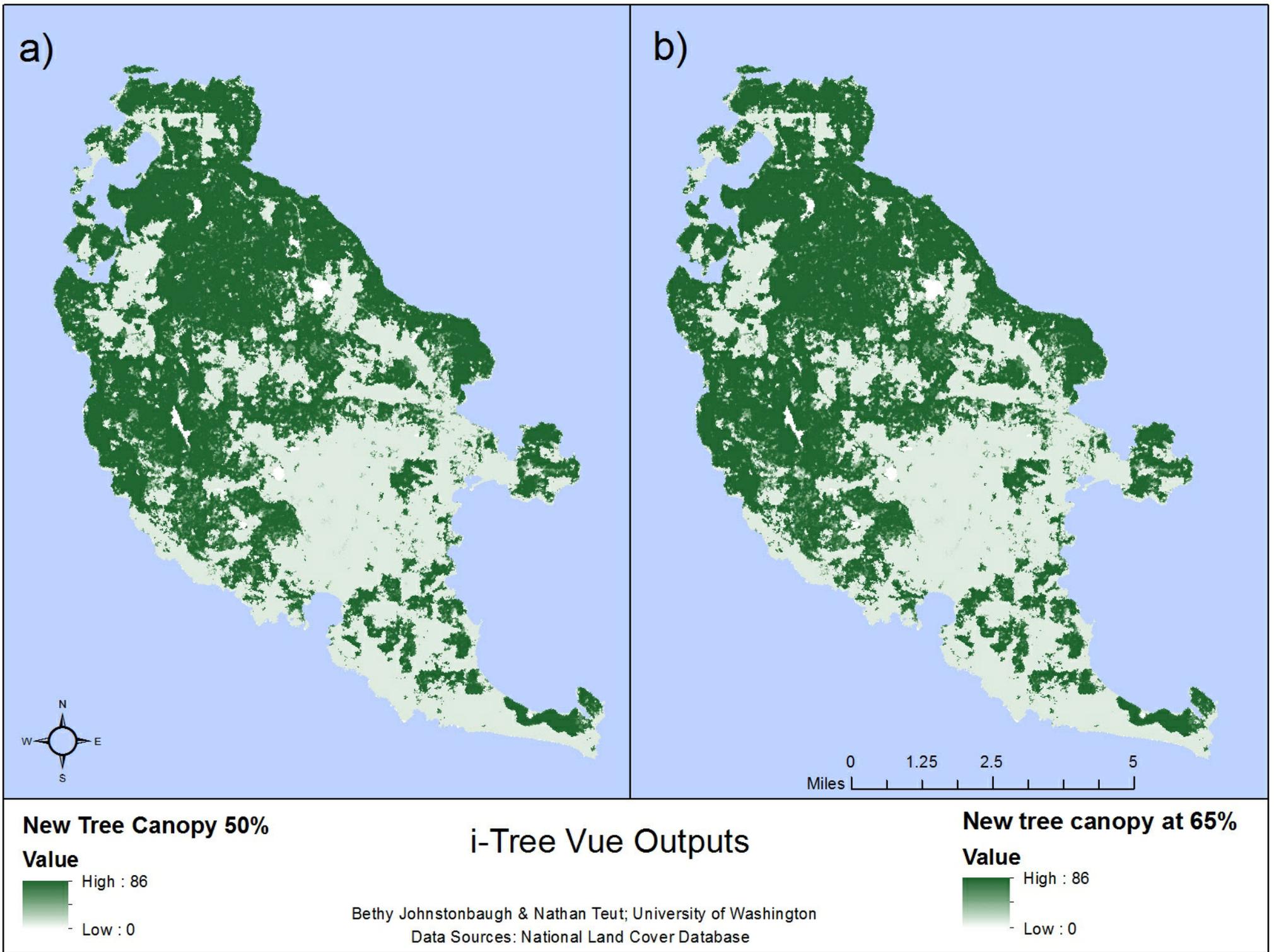


Figure 6: I-Tree Vue forest canopy change scenarios: a) decreased forest canopy b) increased forest canopy coverage

Table 1: I-Tree Vue measurement of carbon sequestration and storage by land cover type.

	LAND COVER						AVAILABLE GREEN SPACE *		GREEN SPACE CANOPY **	CO2			
	Total acres		Impervious Surfaces		Tree Canopy					Annual Sequestration		Total Storage	
	acres	%	acres	%	acres	%	acres	%	%	Tons	\$	Tons	\$
Entire Area	35,585.00	100	1,593.70	4.5	20,527.50	58.1	13,510.40	38.3	60.4	100,709.70	1,956,340.30	3,054,862.00	59,342,321.30
Developed, All Classes	4,347.80	12.2	1,268.70	29.2	1,770.50	40.7	1,518.70	34.9	57.5	8,686.00	168,730.40	263,475.70	5,118,156.30
Open Space	1,359.10	3.8	227.3	16.7	760.3	55.9	462.3	34	67.2	3,730.00	72,457.00	113,143.00	2,197,862.80
Low Intensity	2,581.80	7.3	763.8	29.6	954.3	37	978	37.9	52.5	4,682.10	90,952.60	142,024.20	2,758,896.10
Medium Intensity	315.6	0.9	195.8	62.1	44.7	14.2	76.3	24.2	37.4	219.5	4,263.00	6,656.70	129,309.50
High Intensity	91.4	0.3	81.7	89.4	11.1	12.1	2.2	2.4	114.4	54.5	1,057.80	1,651.80	32,087.90
Forested, All Classes	18,921.80	53.2	198.8	1.1	16,521.00	87.3	2,317.90	12.2	88.2	81,053.70	1,574,511.70	2,458,629.50	47,760,188.20
Deciduous	322.5	0.9	3.6	1.1	260.7	80.9	58.7	18.2	81.8	1,279.20	24,848.20	38,800.90	753,727.80
Evergreen	15,828.10	44.5	165.7	1	14,728.80	93.1	1,042.60	6.6	94	72,260.90	1,403,705.60	2,191,912.70	42,579,071.20
Mixed	1,258.10	3.5	14	1.1	1,157.10	92	93	7.4	93	5,677.00	110,278.00	172,201.20	3,345,099.60
Shrub/Scrub	1,513.20	4.3	15.6	1	374.4	24.7	1,123.50	74.2	25	1,836.80	35,679.90	55,714.80	1,082,289.50
Wetlands, All Classes	3,064.20	8.6	31.9	1	1,129.60	36.9	1,904.20	62.1	37.3	5,541.80	107,652.80	168,101.90	3,265,468.20
Woody Wetlands	1,197.80	3.4	12.1	1	873.5	72.9	313.6	26.2	73.7	4,285.70	83,251.80	129,999.30	2,525,305.80
Emergent Herbaceous Wetlands	1,866.30	5.2	19.7	1.1	256	13.7	1,590.60	85.2	13.9	1,256.10	24,401.00	38,102.60	740,162.30
Agriculture, All Classes	7,456.90	21	76.7	1	912.7	12.2	6,467.60	86.7	12.4	4,477.70	86,981.10	135,822.60	2,638,426.70
Cultivated Crops	10.2	0	0.1	1	1.2	12	8.9	87	12.1	6	117	182.7	3,548.90
Pasture/Hay	7,446.70	20.9	76.6	1	911.4	12.2	6,458.70	86.7	12.4	4,471.60	86,864.10	135,639.90	2,634,877.80
Miscellaneous, All Classes	1,513.40	4.3	17.7	1.2	193.7	12.8	1,302.10	86	13	950.5	18,464.20	28,832.30	560,081.80
Barren Land (Rock/Sand/Clay)	109	0.3	1.5	1.3	15.8	14.5	91.7	84.2	14.7	77.7	1,508.70	2,355.80	45,762.70
Grassland/Herbaceous	1,404.40	3.9	16.2	1.2	177.9	12.7	1,210.40	86.2	12.8	872.9	16,955.60	26,476.50	514,319.10
Water	280.9	0.8	n/a	n/a	n/a	n/a							

\*Available Green Space: Total Land(100) - % Impervious Surface - % Canopy  
\*\*Canopy Green Space: (Tree Canopy / (Tree Canopy + Available Space))

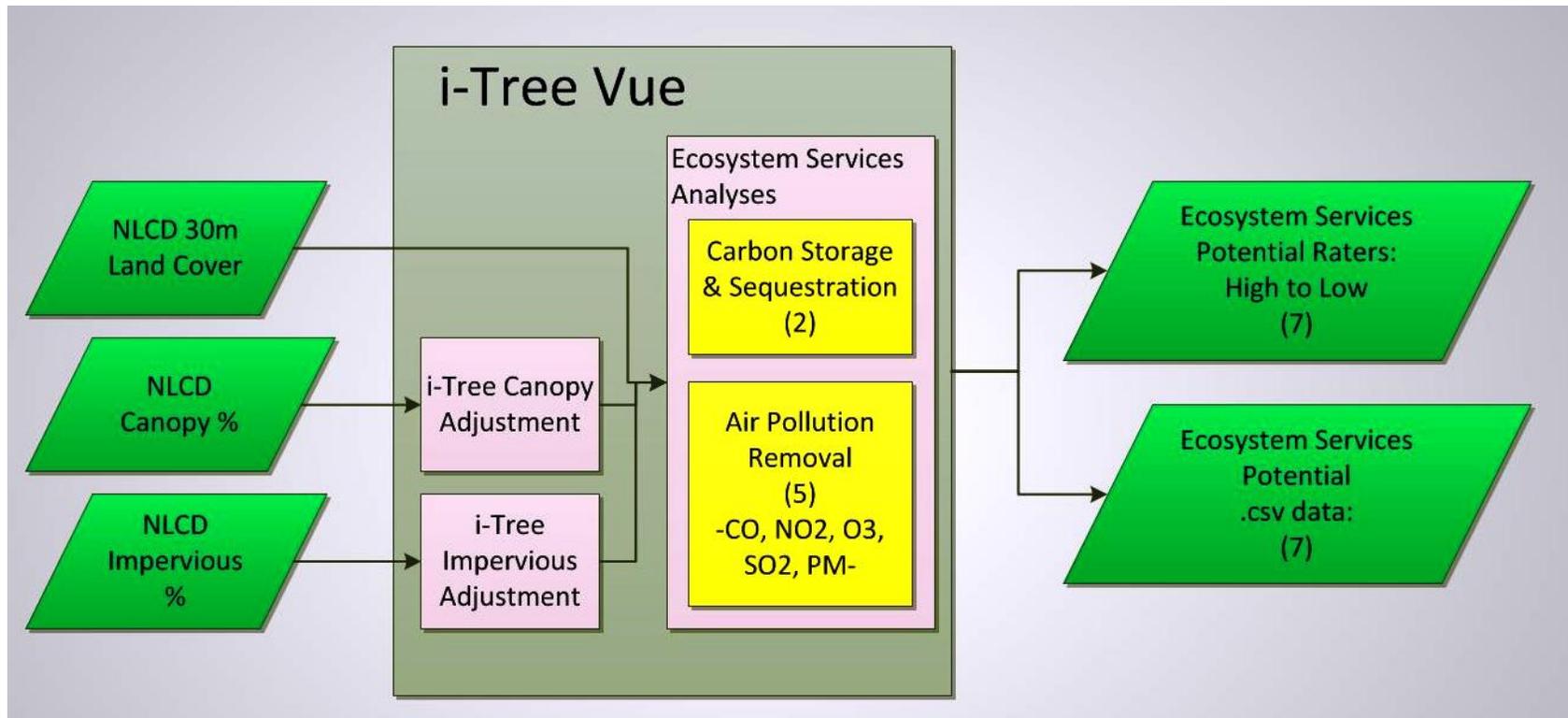
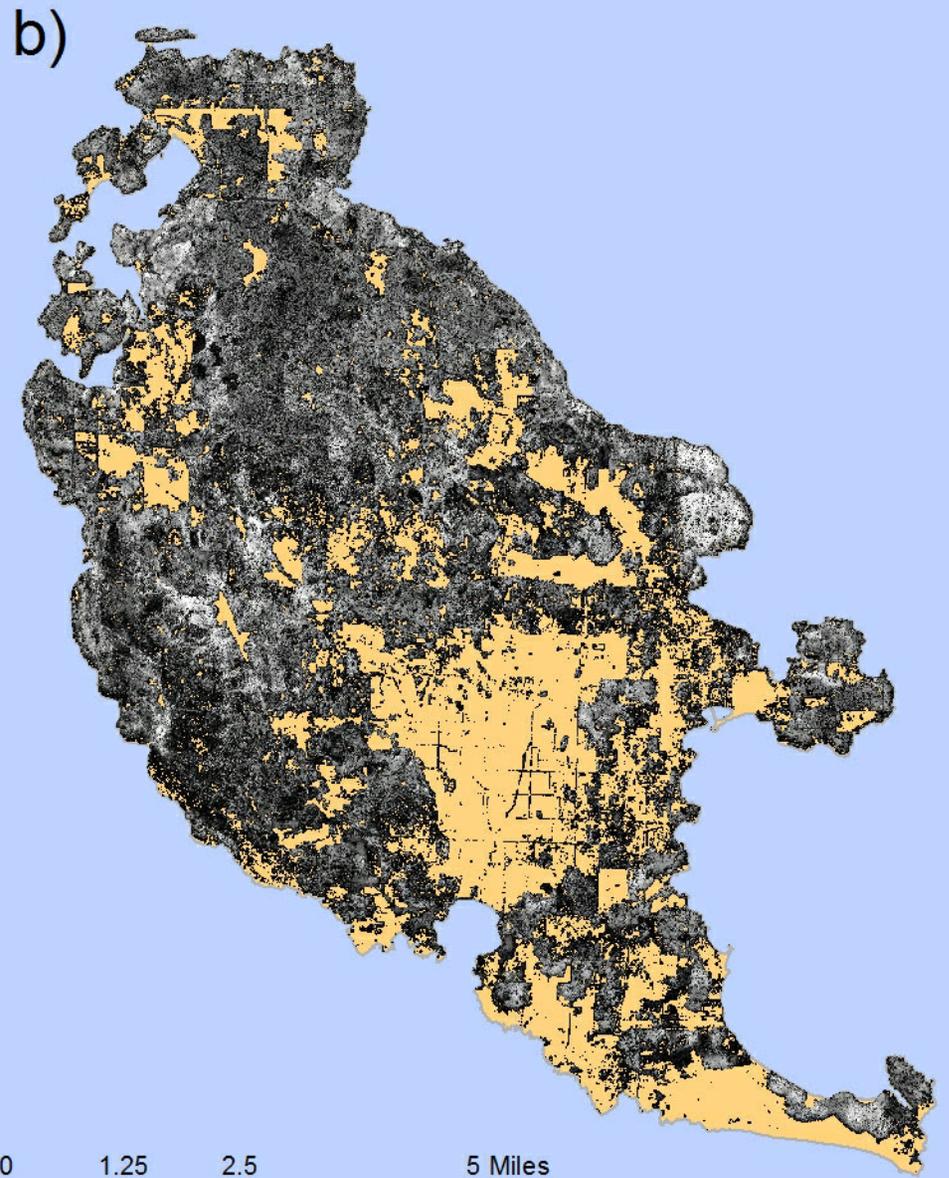
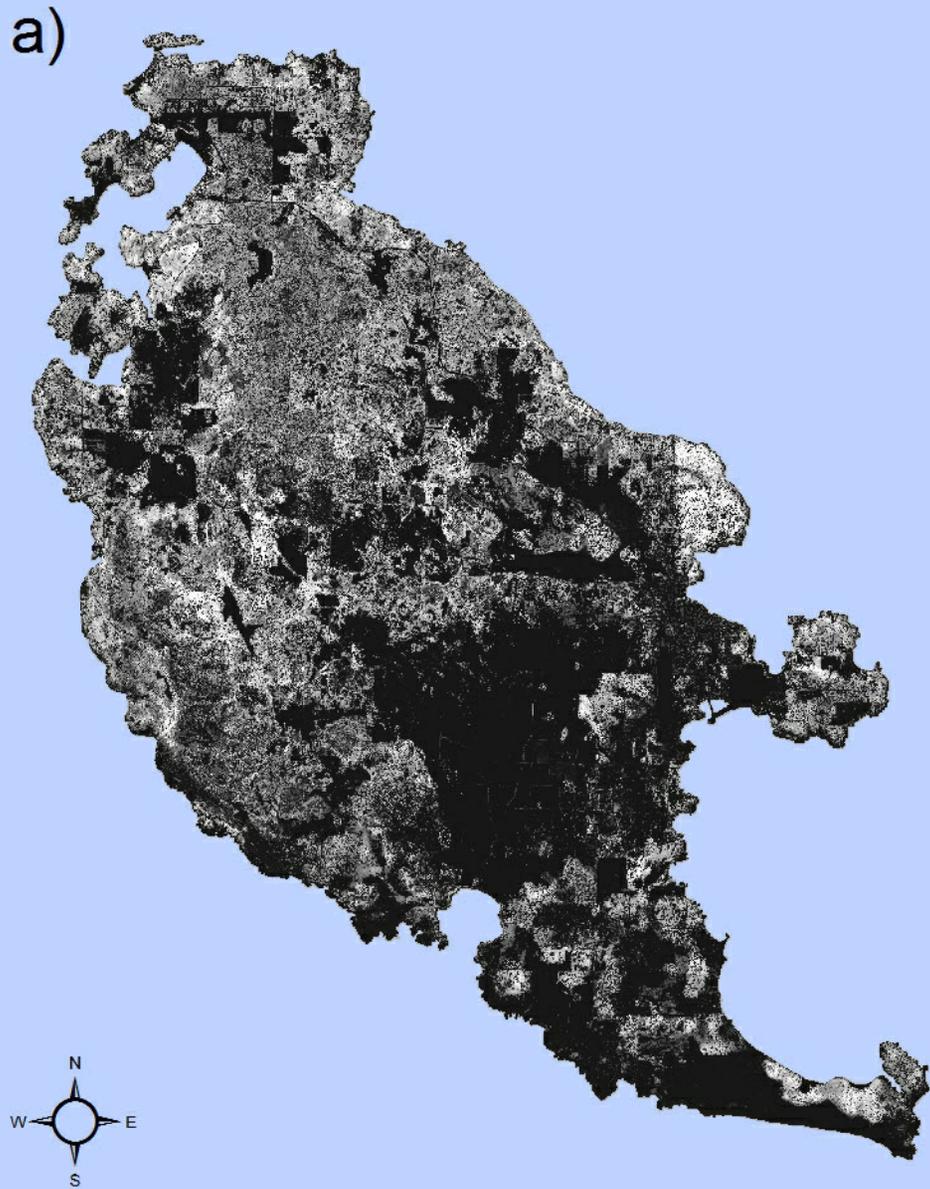
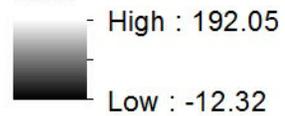


Figure 7: I-Tree Vue workflow diagram



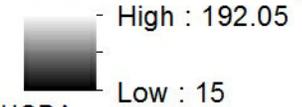
**Vegetation Height**

**feet**



**Vegetation Height**

**min 15 & buildings removed**



Bethy Johnstonbaugh & Nathan Teut; University of Washington

Data Sources: Puget Sound Lidar Consortium & National Aerial Imagery Program, USDA

Figure 12: Vegetation height outputs from ArcMap hydrology tools.

## *ArcMap.*

The analysis in ArcMap delineated trees from high resolution LiDAR derived DEMs. A toolbox was also created in order to streamline and automate a repeatable process. The toolbox contains eight ModelBuilder models (Fig 8).

The vector representation of individual trees produced by ArcMap hydrology tools were the most exciting data gathered by this study (Fig 9).

Approximately 2.7 millions trees were identified. Model 1 simply creates a “vegetation height” raster from the bare earth and top hit DEMs. Model 2 delineates the individual trees in the study area by inverting the vegetation heights, and then using hydrology tools available in Spatial Analyst. This is limited by a user defined minimum height which removes non-forested area from the raster coverage. (Fig 10)

The land cover raster created in SPRING eliminated false positives caused by rooftops, as shown in Model 3. Model 4 finally assigns the approximate height values to the tree points. (Fig 11)

The vegetation height outputs (Fig 12,13) show a similar geographic distribution of trees to that which

appeared in the forest cover outputs of SPRING and i-Tree. But new patterns become visible when tree heights are represented. Notice that the tallest forest is in the University of Washington’s biological reserve, which has been protected since 1921. The forested areas of the San Juan Island National Historical Park are also exceptionally tall. The tallest areas do not correspond to areas with lower density of trees per acre, which we expected because the forests are immature and the trees have plenty of space left to grow.

The raster data summarizing the individual tree vectors (Fig 13) are comparable to forest cover rasters but more sensitive. For example, the pastureland in the center of the island is crisscrossed by scrubby hedgerows, which are only visible in the ArcMap output. Model 5 generates the trees per acre and the average tree heights per acre rasters (Fig 14).

Model 6 uses tree polygons (vector analysis) to calculate forest canopy cover percent per acre (Fig 14), and Model 7 does the same but using the minimum vegetation heights with false positives removed (raster analysis) (Fig 15). Finally, Model 8 generates the estimated above ground biomass per acre raster based on Lefsky’s regression analysis equation using the

average height raster and forest cover percent raster (Fig 15).

The two methods for calculating forest canopy cover, from tree polygons or vegetation pixels, create virtually indistinguishable maps (Fig 16). The maps of above ground biomass derived from them are similarly indistinguishable (Fig 17). The vector method creates a slightly higher estimation of above ground biomass (3,875,731.66 mg/ha) than the raster method (3,800,371.21 mg/ha) but with 84% certainty at best,

the values are not significantly different. Since these two values are so close, we recommend using the raster method in Model 7 in the interest of saving time. Model 7 runs in about a minute while Model 6 requires over twenty minutes. Running both Models, though, allows results to be cross-checked.

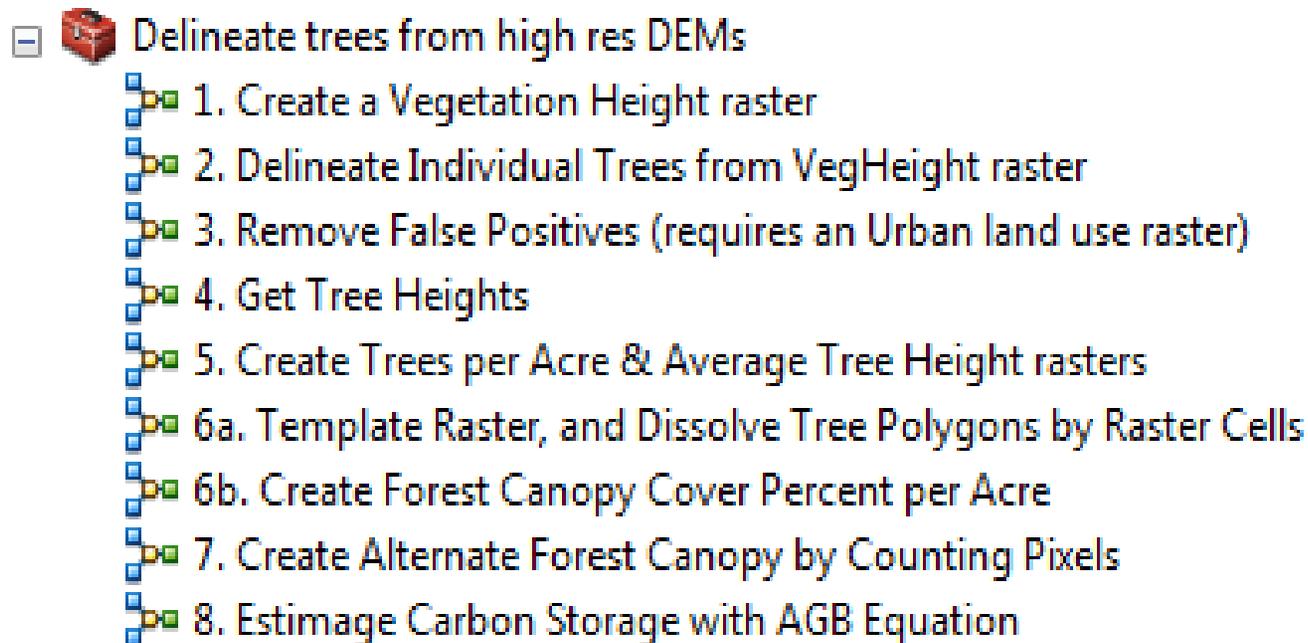
- 
- [-]  Delineate trees from high res DEMs
    -  1. Create a Vegetation Height raster
    -  2. Delineate Individual Trees from VegHeight raster
    -  3. Remove False Positives (requires an Urban land use raster)
    -  4. Get Tree Heights
    -  5. Create Trees per Acre & Average Tree Height rasters
    -  6a. Template Raster, and Dissolve Tree Polygons by Raster Cells
    -  6b. Create Forest Canopy Cover Percent per Acre
    -  7. Create Alternate Forest Canopy by Counting Pixels
    -  8. Estimate Carbon Storage with AGB Equation

Figure 8. ArcMap toolbox

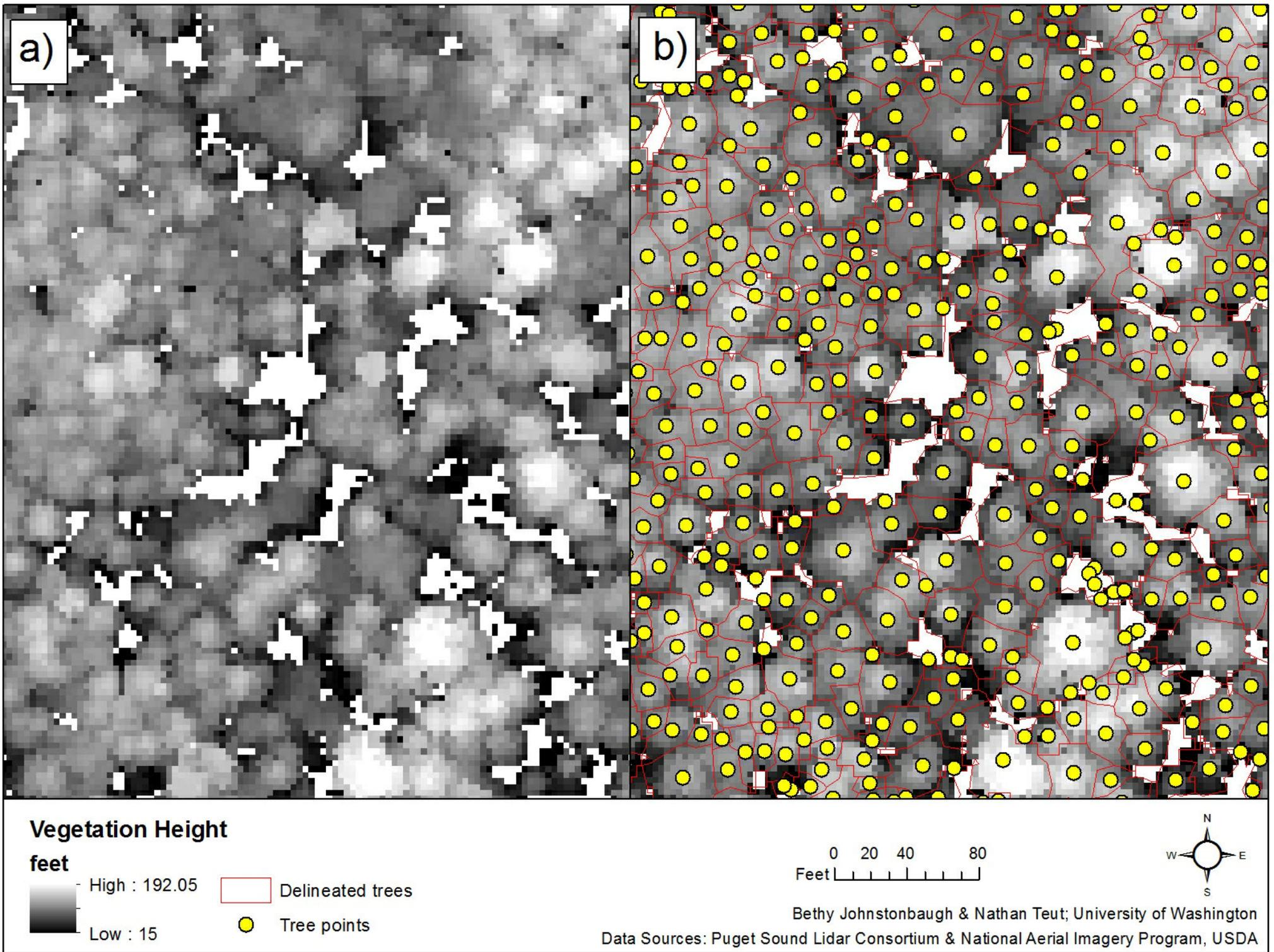


Figure 9: a) LiDAR derived vegetation height raster b) LiDAR derived vegetation height raster with delineated tree polygons and points.

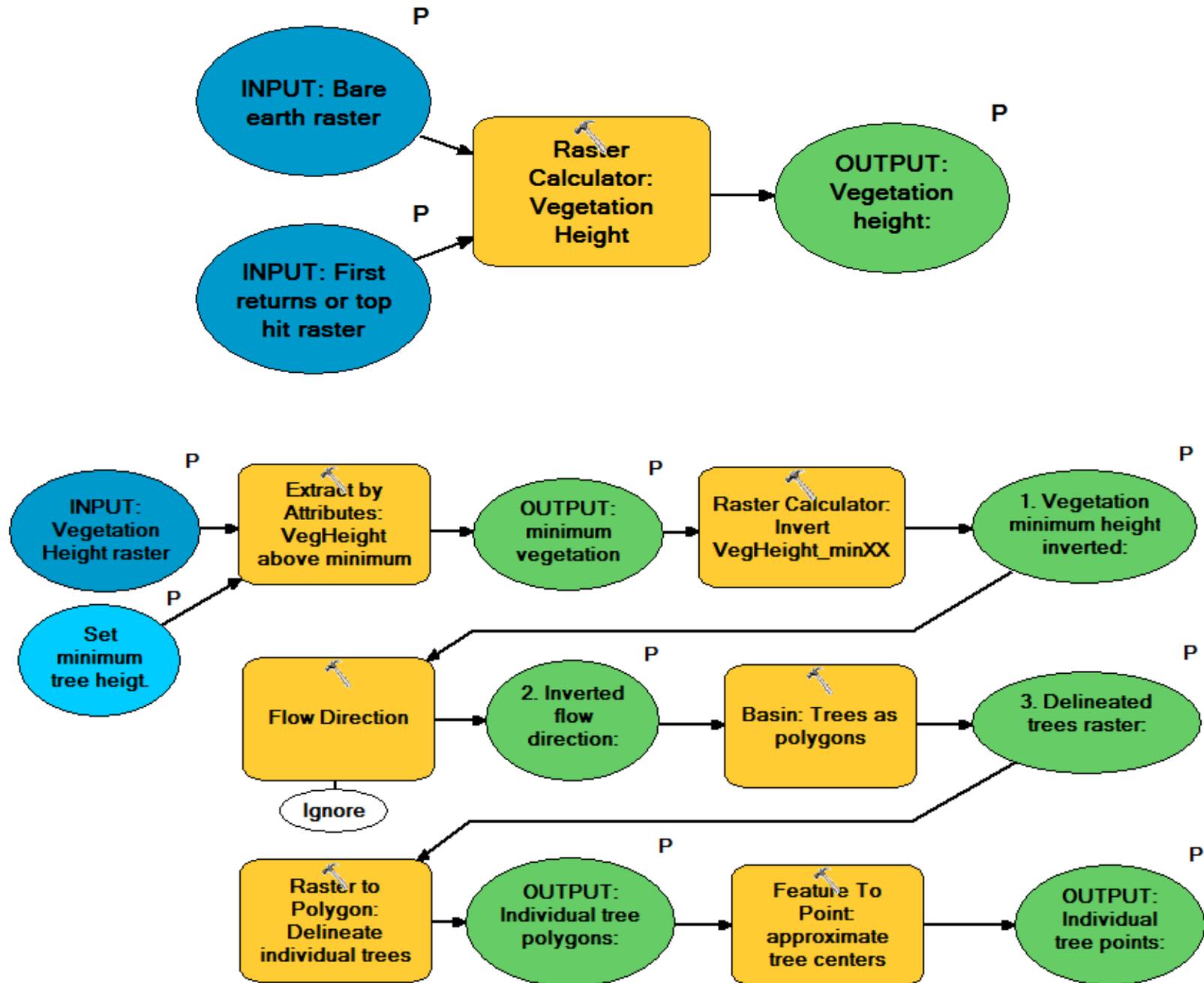


Figure 10: ModelBuilder diagram of Model 1 and Model 2

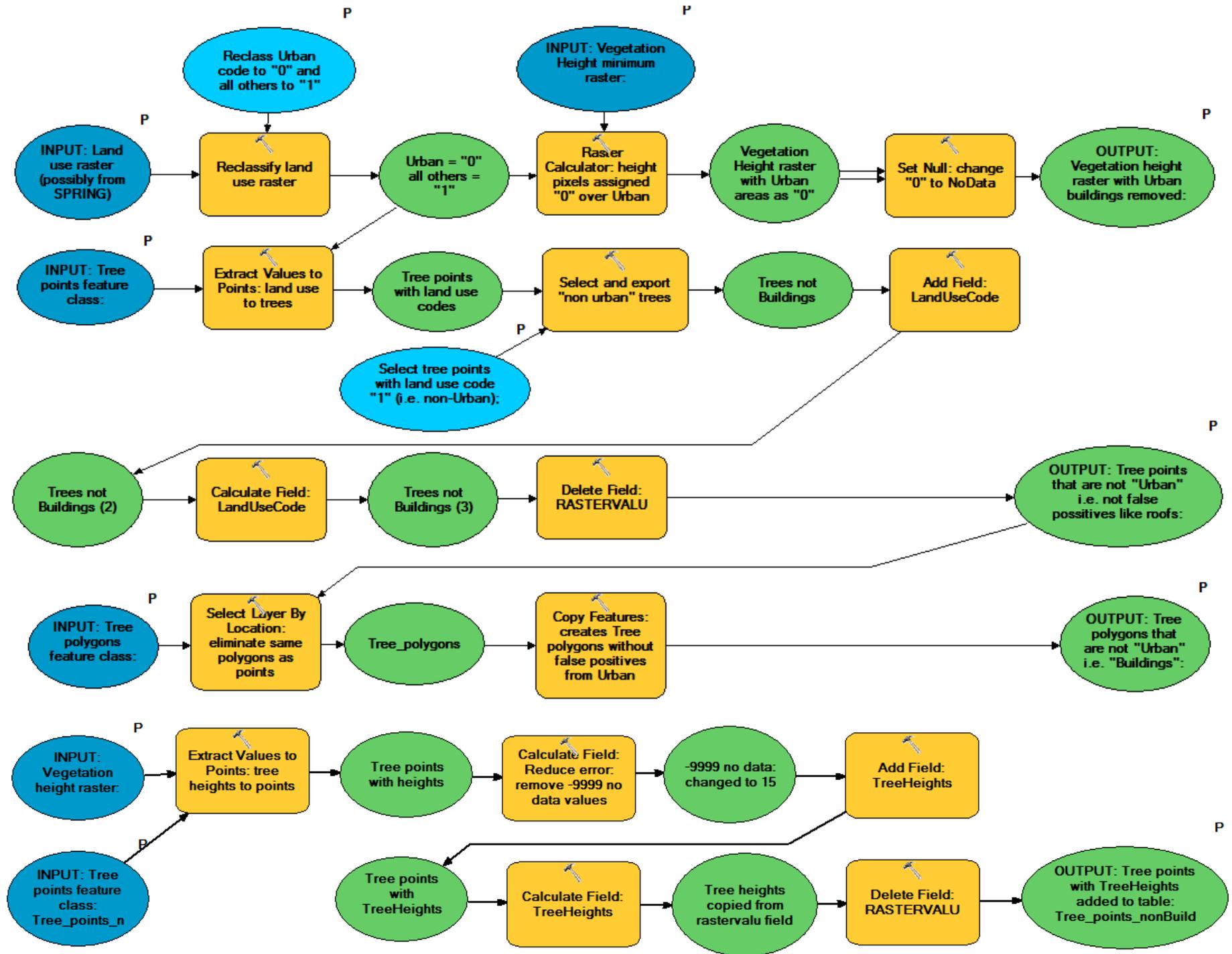


Figure 11: ModelBuilder diagram of Model 3 and Model 4.

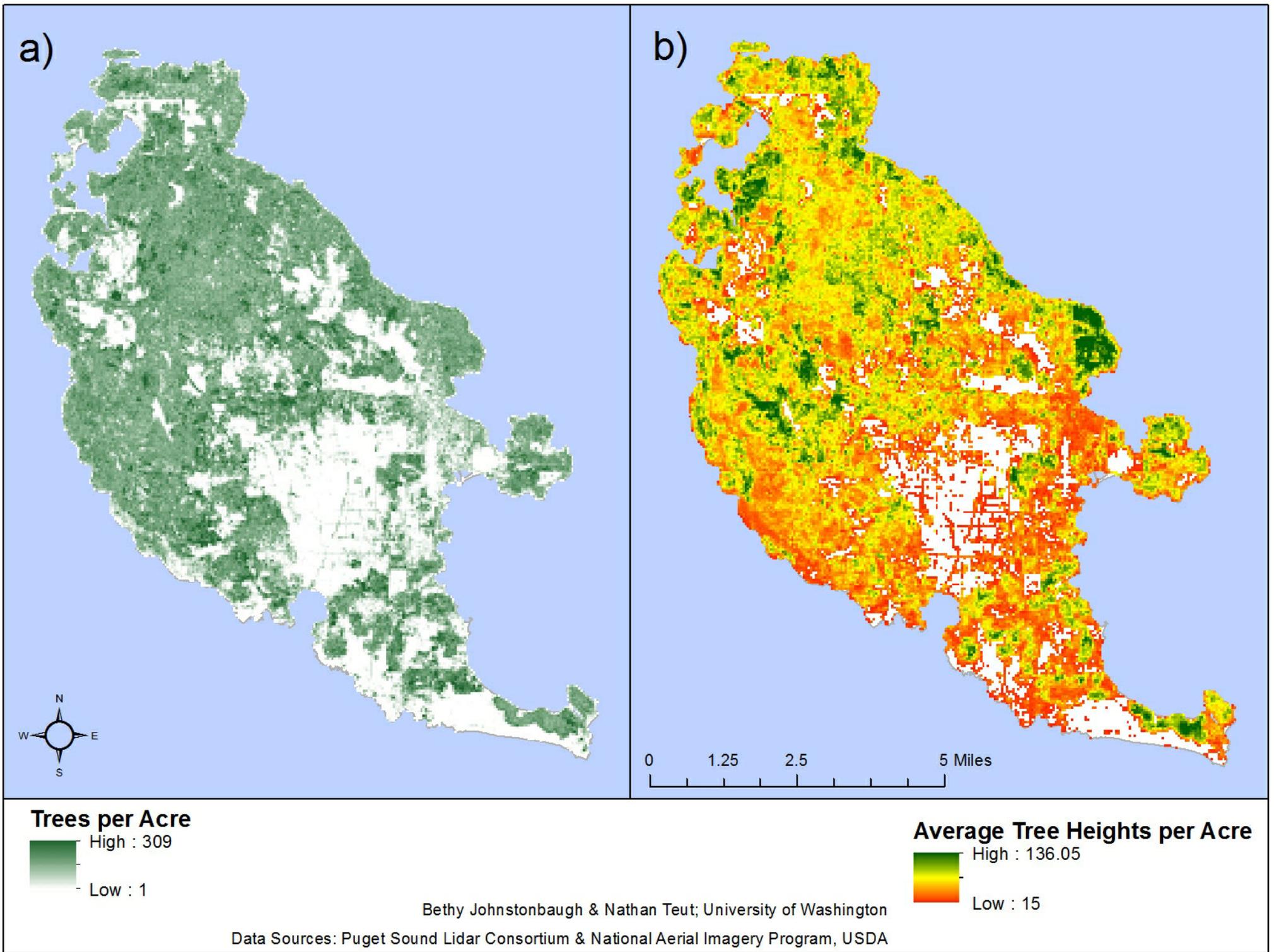


Figure 13: Tree counts and average tree height rasters output from ArcMap.

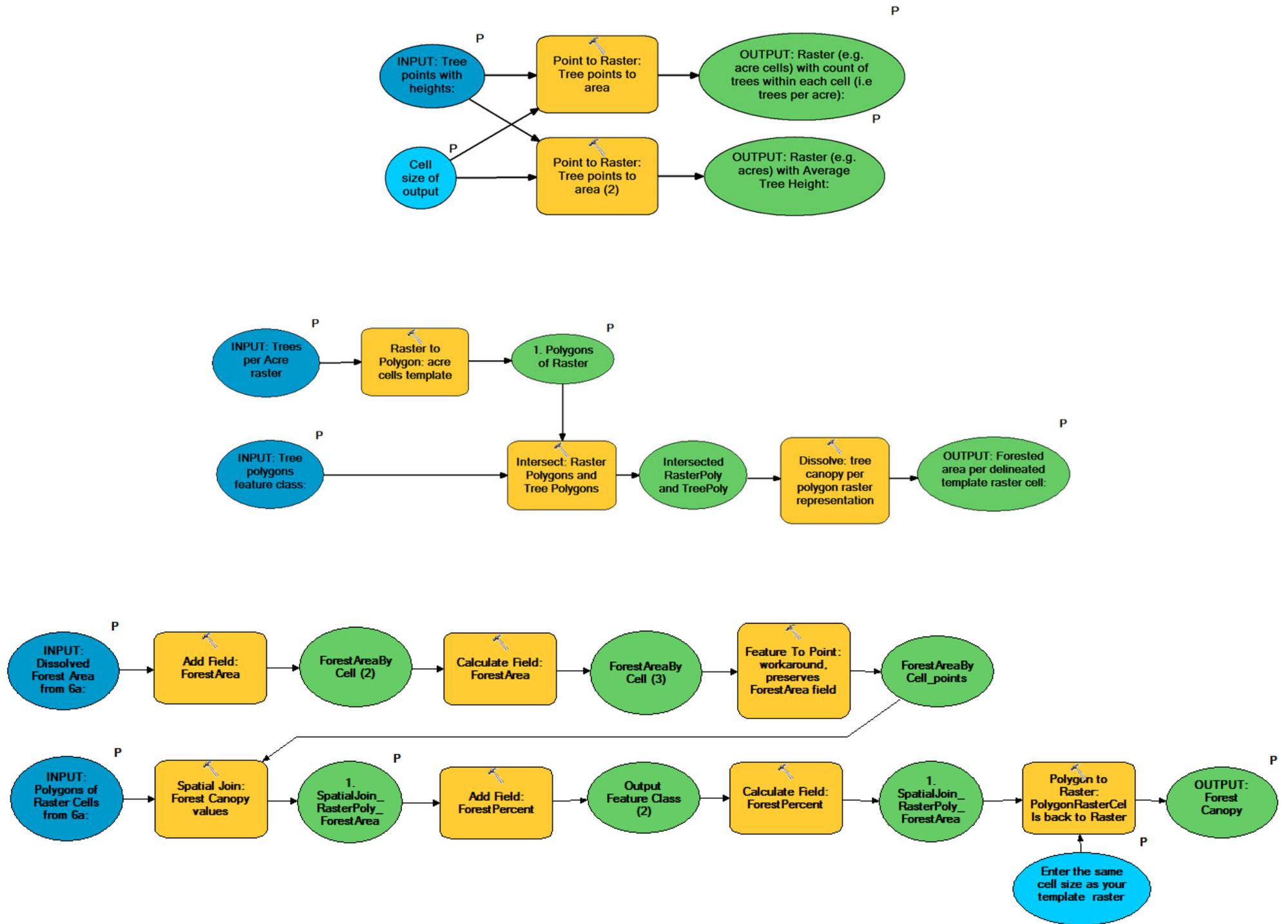


Figure 14. ModelBuilder diagrams of Model 5 and Model 6.

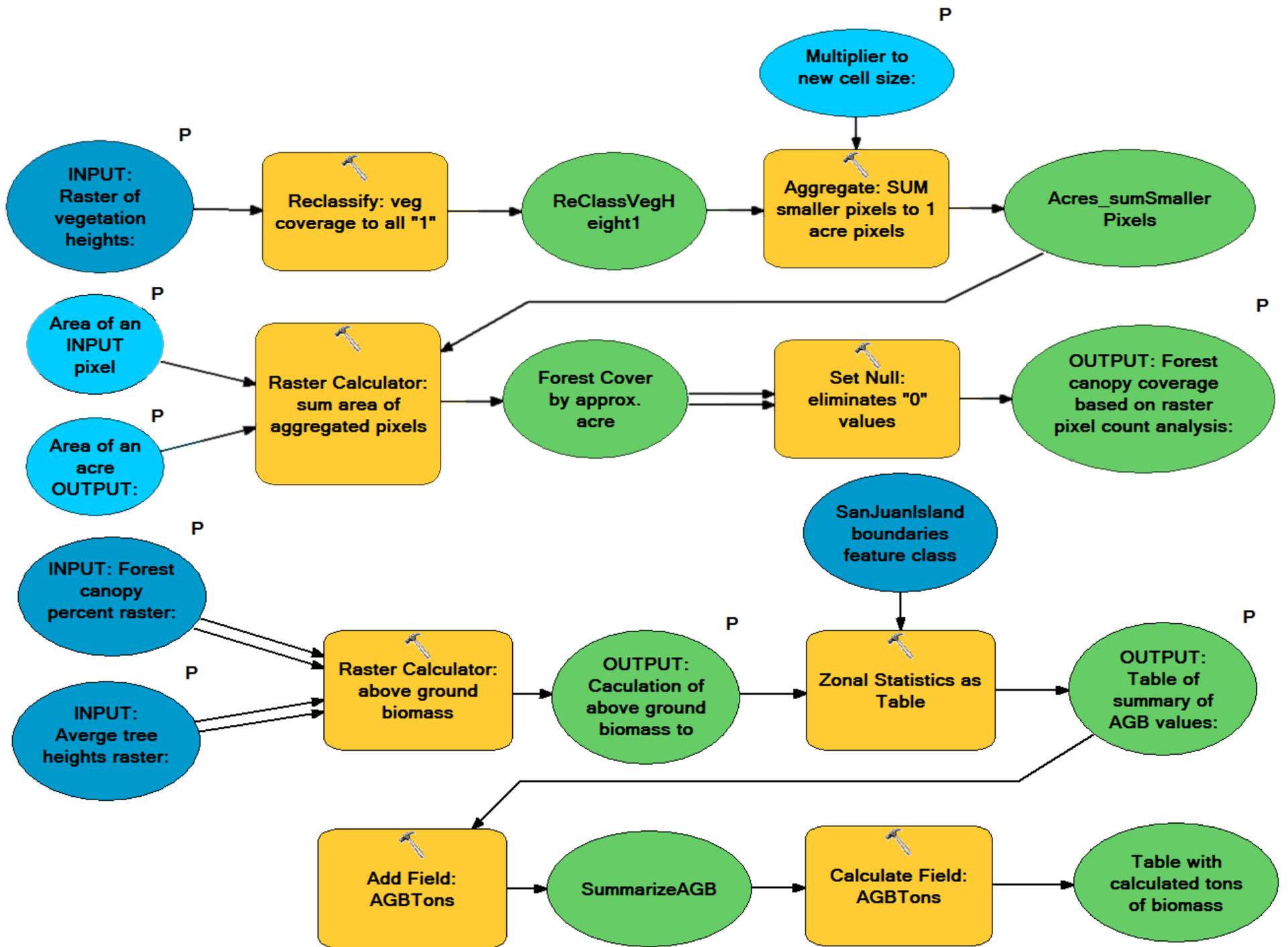


Figure 15. ModelBuilder diagrams of Model 7 and Model 8.

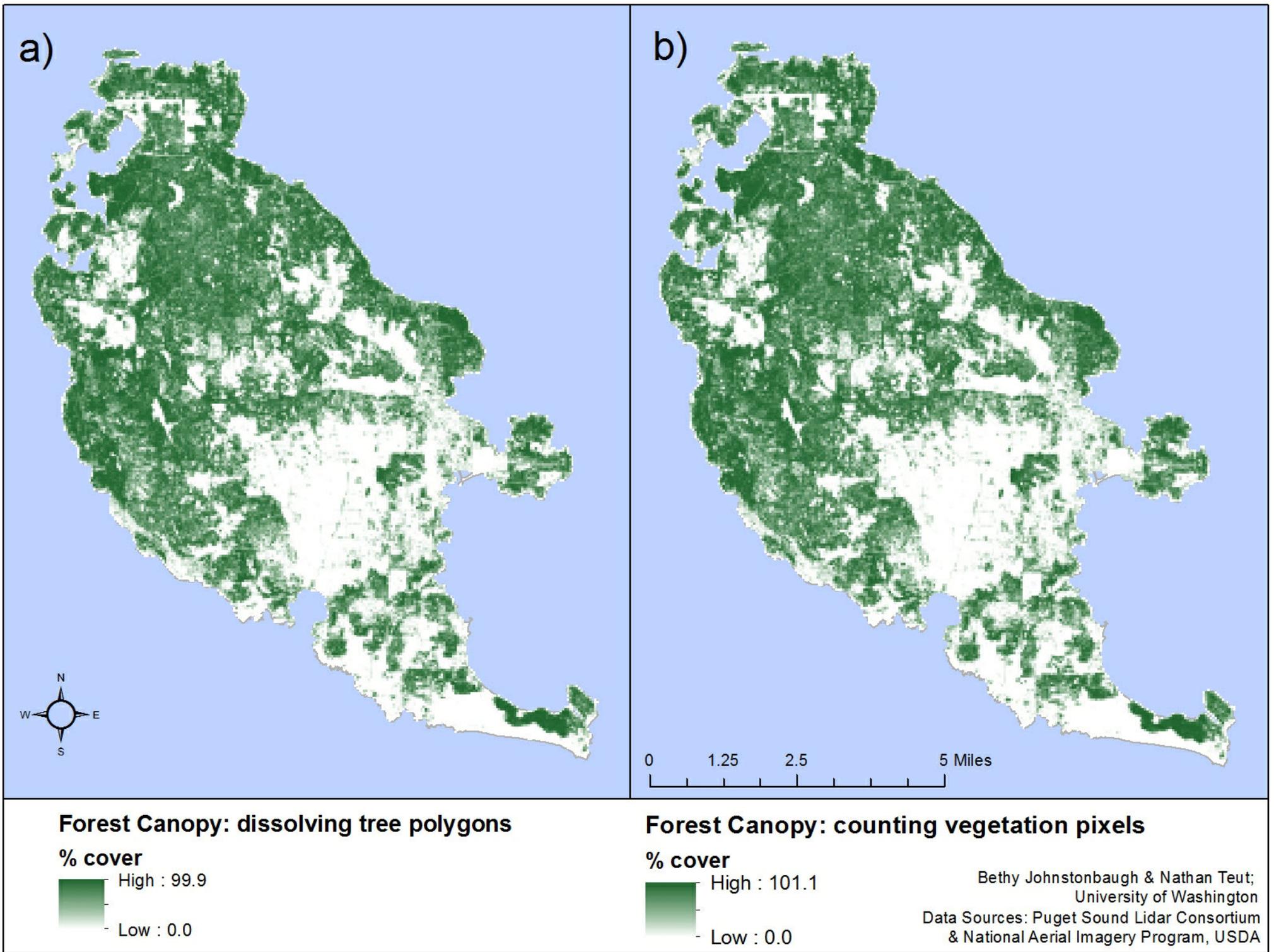
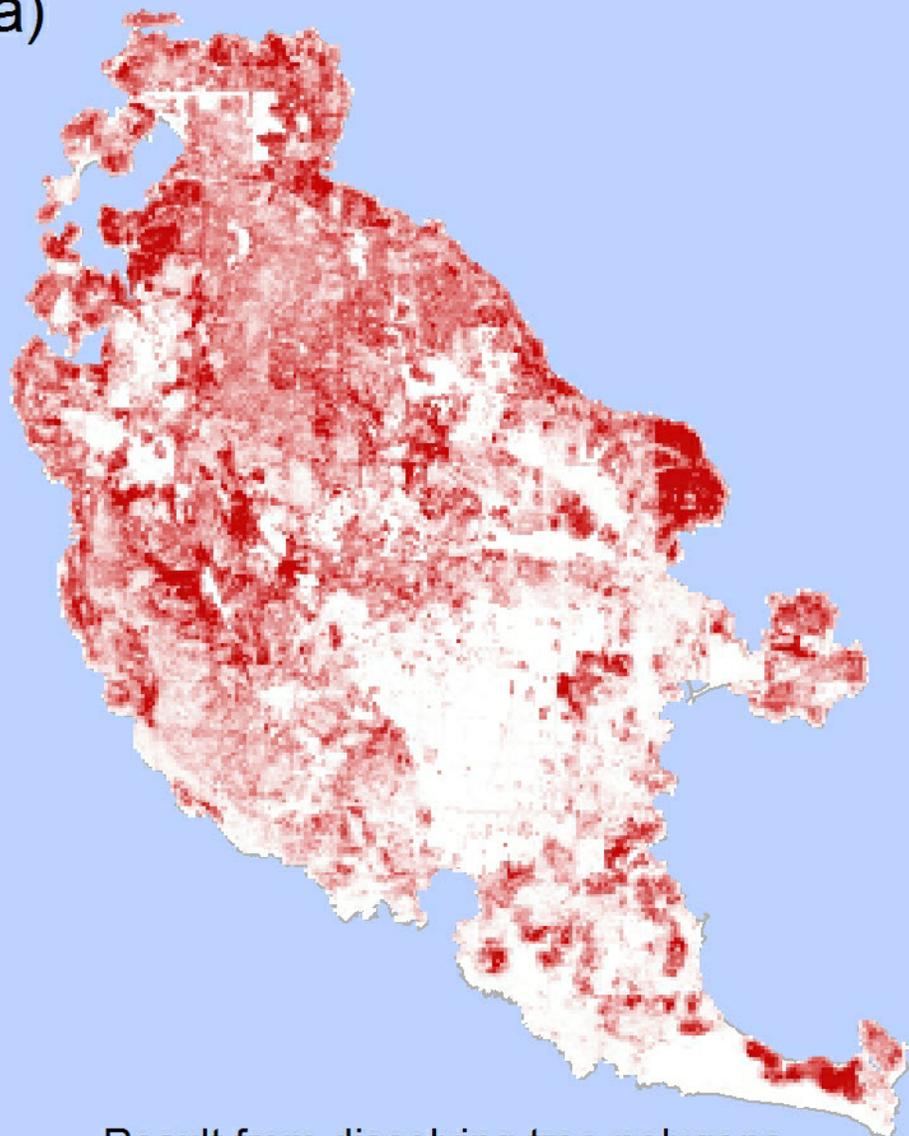


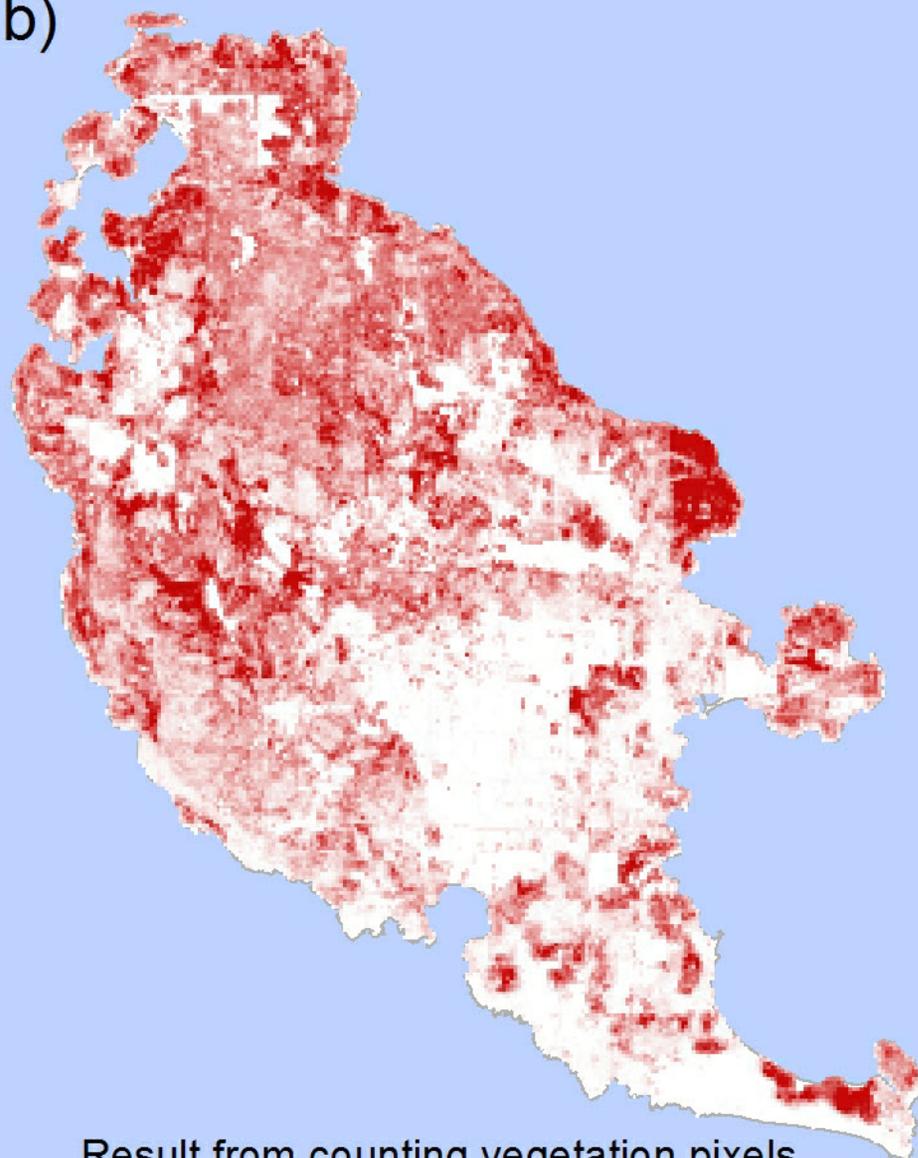
Figure 16: Forest canopy coverage rasters

a)



Result from dissolving tree polygons.

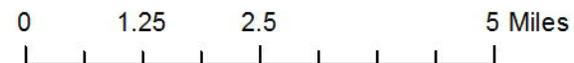
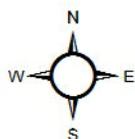
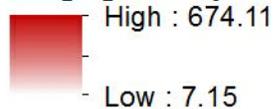
b)



Result from counting vegetation pixels.

**Calculated Above Ground Biomass**

**Megagrams per acre**



Bethy Johnstonbaugh & Nathan Teut; University of Washington

Data Sources: Puget Sound Lidar Consortium & National Aerial Imagery Program, USDA

Figure 17: Above ground biomass rasters output from ArcMap.

### *Recommended Course of Action.*

The workflow presented here weaves together several methodologies and remote sensed data sources. Fusion and SPRING create rasters which can be analyzed with the ArcMap toolbox. I-Tree provides an alternative analytical track. (Fig 18) They should be used to survey all the forests of San Juan County in greater detail.

Although these remote sensing methods are powerful, ground-truthing will be an important component in the next stage of the study. Botanical ecologists need to survey the forests from the ground up. Because we focused on freeware and free data, the only cost would be labor. Kwiaht's executive director estimates that continuing this study with improved accuracy would cost approximately \$33,553 (Table 2).

New orthophotos of San Juan County were collected during the summer of 2013. As soon as these images are available, Kwiaht should use SPRING to create a very detailed land cover raster, detailing different forest types. Any volunteer could easily learn to identify pixels, and many of Kwiaht's regular volunteers are comfortable studying aerial imagery. They also have a collective pool of local knowledge about forests they

regularly explore. Entering more "training" points will make the result more accurate. They could also produce a much more complex result than the "test run" produced by this study.

As mentioned earlier, the land cover raster will serve many purposes. The "Urban" class may be the best picture of impervious surfaces available in San Juan County, and it can be used to distinguish building peaks from treetops in the LiDAR analysis. A high resolution remote-sensed land cover raster could provide a lot of information about the habitat types provided by public lands and reserves. It would be particularly invaluable on small outlying islands which are difficult to reach, and where fieldwork could cause significant ecological disturbance.

The ArcMap toolbox for delineating trees from DEMs is ready for action. But the only available LiDAR data is from 2009. A botanist needs to measure tree height and tree location on sample plots (Fig 19), to see how much the forest has changed over the last four years. How many trees have been cut down? How much taller have the trees grown? Only ground-truthing can answer these questions and quantify the error and uncertainty in the LiDAR analysis.

Biomass is the easiest metric of carbon to use. Allometric equations in the literature most commonly calculate above ground biomass, not carbon storage or carbon sequestration. The biomass of plant tissue samples could also be measured with laboratory equipment Kwiaht already owns. In fact, they regularly measure the biomass of plankton samples; perhaps someday this project will expand to study the other major carbon sink in San Juan County.

I-Tree will put a price tag on the biomass of the forests. Modeling the effects of offering tax breaks for forests might be a more pragmatic way to measure the monetary value of ecosystem services. However, an outreach and education program should be included in the study, because it is crucial that stakeholders, particularly land owners and public officials, understand what they are buying.

Table 2. Itemized budget projection for labor costs in the next phase of the study.

<b>Job Category</b>	<b>Current Average Hourly Rate (\$/Hour)</b>	<b>Fringe</b>	<b>Burdened Hourly Rate</b>	<b>Expected Hours</b>	<b>Expected Cost</b>
Executive Director	\$3.15	0.00%	\$3.15	120	\$381.15
Botanist/Ecologist	\$28.00	0.00%	\$28.00	390	\$10,948.00
GIS Analyst	\$24.00	0.00%	\$24.00	350	\$8,424.00
Skilled Volunteer	\$0.00	0.00%	\$0.00	200	\$0.00
Lawyer	\$0.00	0.00%	\$0.00	5	\$0.00
CPA	\$30.00	0.00%	\$30.00	10	\$330.00
Intern/Apprentice	\$7.50	0.00%	\$7.50	370	\$2,782.50
Journal Article Author	\$26.00	0.00%	\$26.00	35	\$936.00

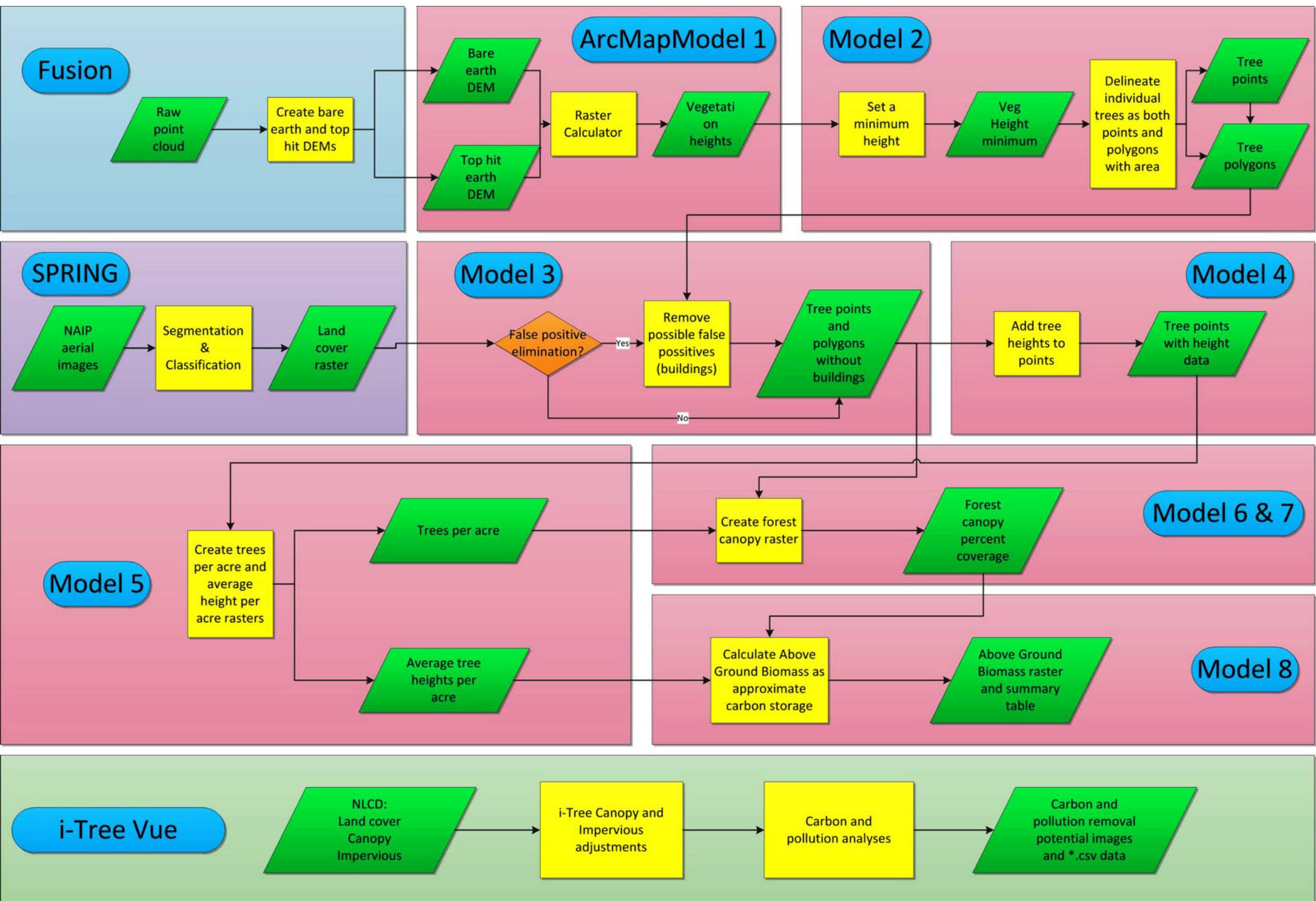


Figure 18: Overall workflow diagram integrating Fusion, Spring, ArcMap, and i-Tree.

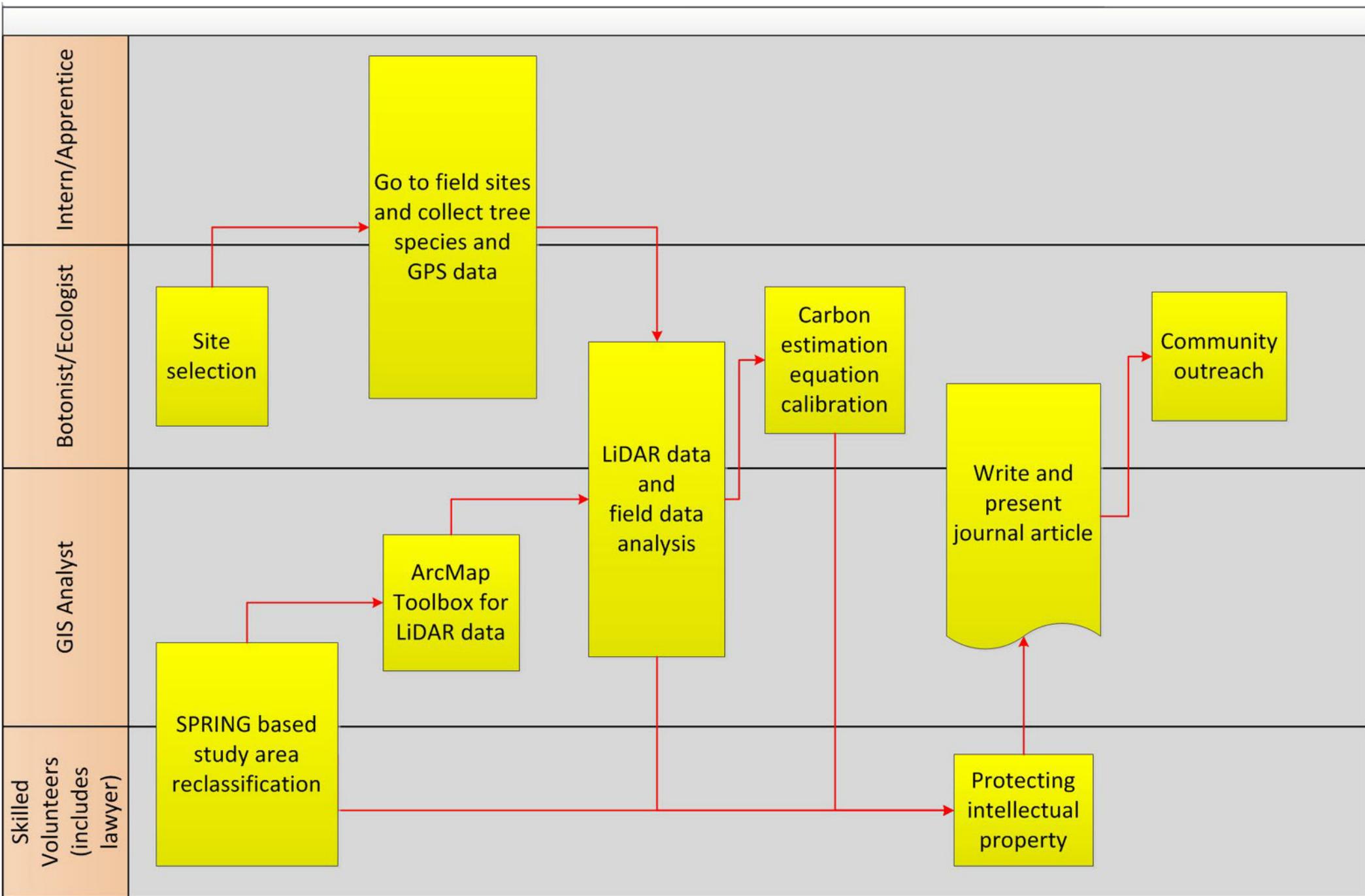


Fig 19: Swimlane diagram detailing the roles of GIS analyst, botanist, and other Kwiacht staff in extended study.

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## Appendix A. Software Tips

### SPRING:

The National Agriculture Imagery Program data collected for this analysis was from the USDA Geospatial Data Gateway website (<http://datagateway.nrcs.usda.gov>). This data is an aerial photography mosaic of the majority of the United States with a 1 meter cell size resolution. ArcCatalog can also directly connect to their GIS servers through this URL: <http://gis.apfo.usda.gov/arcgis/services>. The projection chosen by this agency is Nad83 UTM Zone 10N, Albers Conformal Conic. This is important to note, as applying the products to other datasets in ArcMap could require care in reprojecting data.

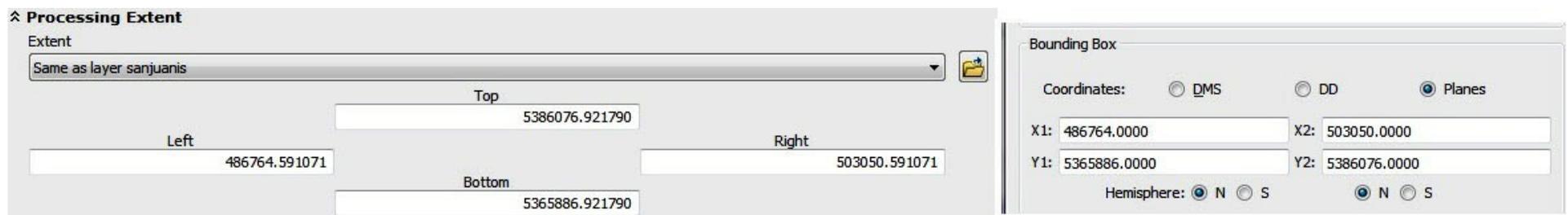
Although NAIP 4-band data is collected, this report used 3-band data. The online system for attaining 4-band data was out of order, as well as there being an extra financial cost in attaining 4-band data. The fourth band is a near-infrared spectrum that is extremely good for detailing plant growth in the imagery.

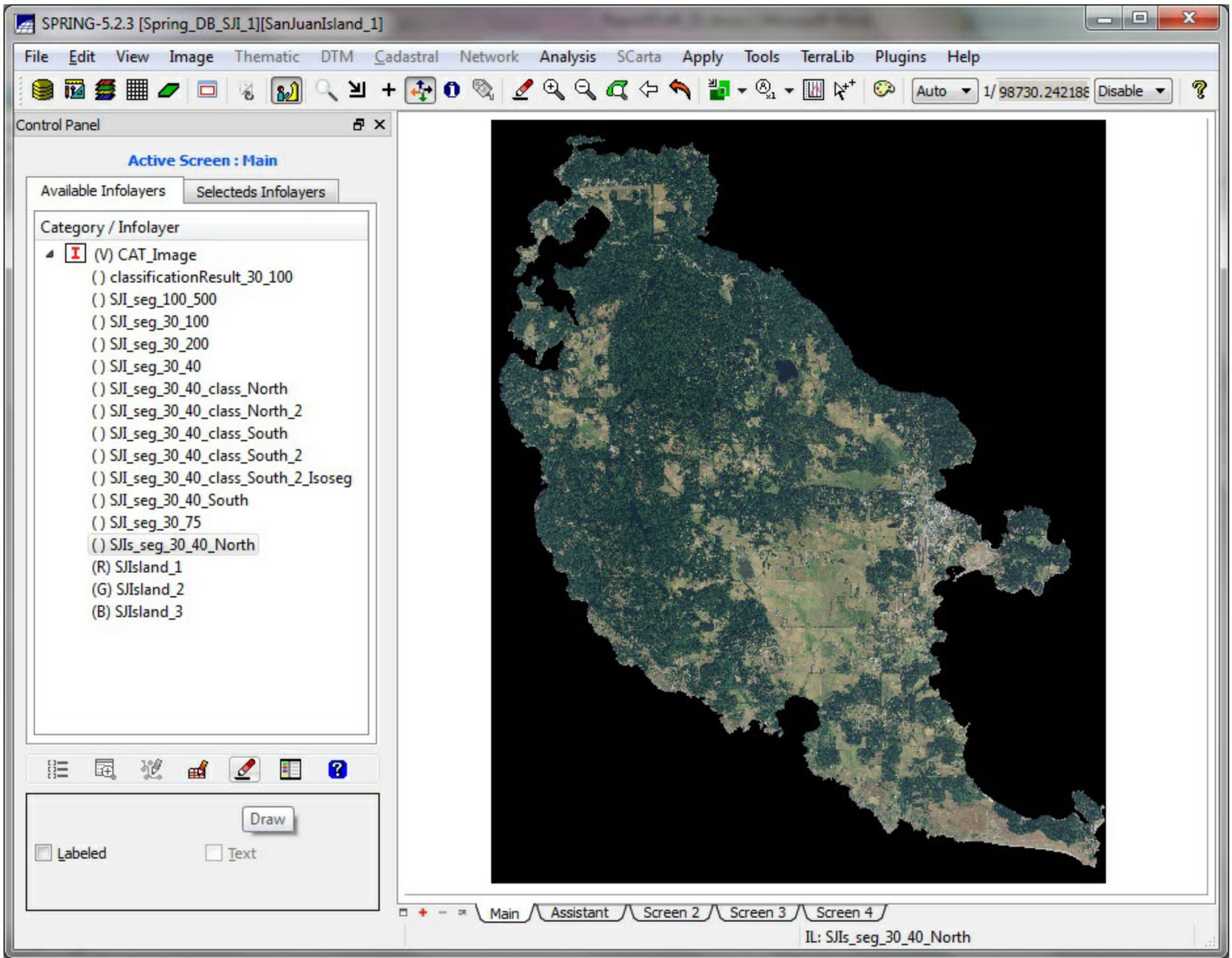
As a general note on SPRING, only the 32 bit version works, and it is a touchy program overall, and has trouble processing large images. The NAIP imagery for San Juan County is several gigabytes. Extracting a smaller area of an

the image to limit the file size can be done in ArcMap. Next, the image is exported from the ArcGIS environment as a georeferenced \*.tif file.

After downloading and installing SPRING, a new database is created (File > Database...) to house all the data and outputs, a new Project is started in the software to begin work with our 3-band image (File > Project...), and the image is loaded into the software (File > Import > Import Vectorial and Matricial Data).

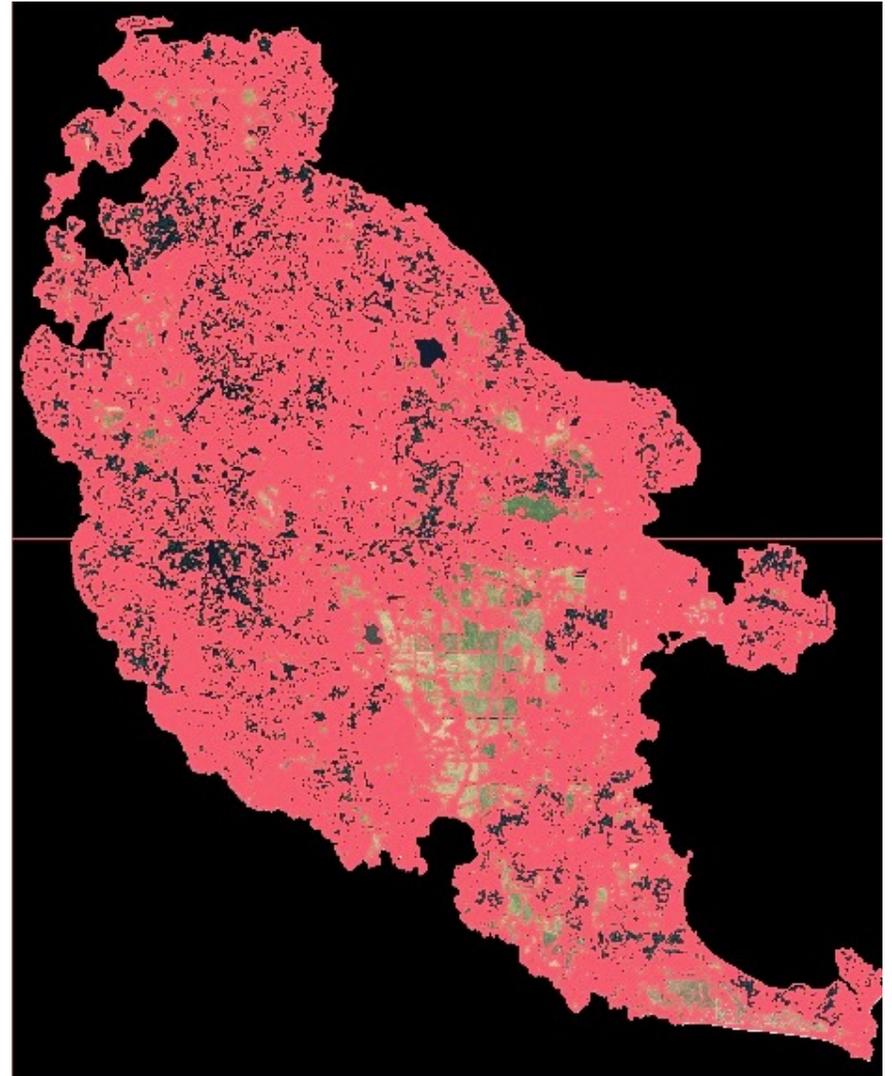
SPRING requires the projection of the image to be set manually in the New Project window. NAIP data is in the Nad83 UTM Zone 10N projection, and must be entered accordingly. Also, SPRING needs to know the spatial extent of the project to examine, and this is set in the "Bounding Box" section in the window. The extent can be copied from the extents given in ArcMap for extracted image. After setting these parameters, the image can be loaded.





After entering the projection, extent, and the image itself, conduct a segmentation (Image > Segmentation). Segmentation automatically divides the image into “objects”, or features. In the Segmentation window, all three bands were selected at the top. This window is also where you enter the “Similarity” and “Area” values. Similarity will “tell” SPRING how similar the pixels need to be in order to be grouped together. A lower similarity value will result in a more detailed segmentation. Area “tells” SPRING the minimum number of pixels allowable to be segmented as a single feature. This segmentation process requires many runs at different values for the two parameter so you can get a feel for the resulting level of detail in the segmentation.

As noted earlier, SPRING is touchy about data size of the imagery. Because of this, the segmentation and classification steps in this analysis had to be completed by halving the island. The original imagery was left loaded as normal, but in the segmentation window, the Bounding Box was adjusted. Simply find the midpoint of the Y1 and Y2 points, enter it in Y1 or Y2 such that the island is split (for processing by SPRING) into north and south halves. Unfortunately, this means added time in processing the island overall because you have to do it twice (north and south), however, it is an effect work around. The alternative is to have SPRING simply close itself without warning or explanation.

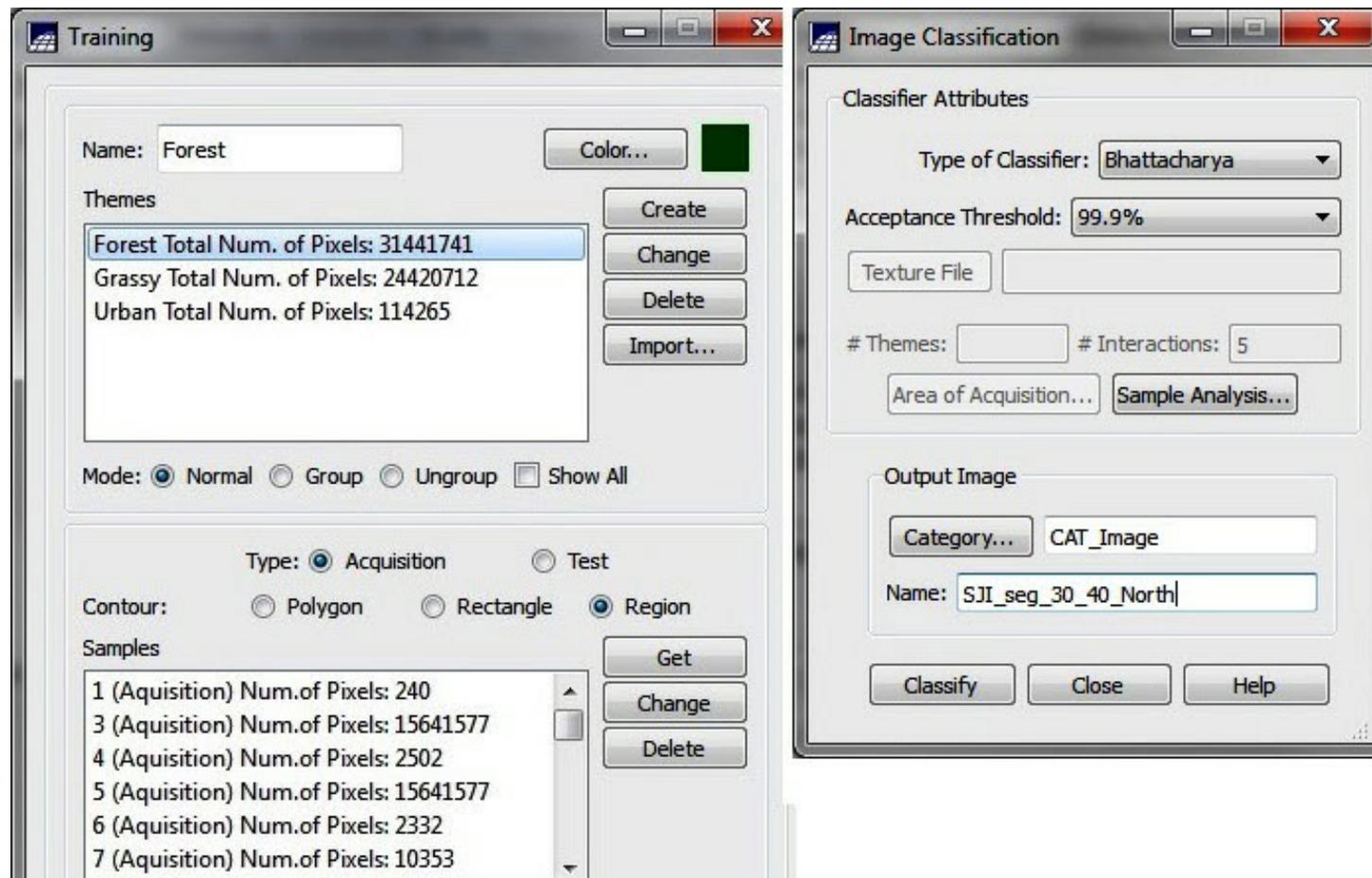


The island image was then classified, via segmented features. Under advisement from the project sponsors, this analysis only includes three land use types: Forest, Grassy or Non-Forest, and Urban. Urban is a catch-all for impervious surfaces like roads and buildings. Delineating the buildings is especially helpful in the ArcMap Model Builder exercise of forest delineation to remove false positives for trees that were actually structures.

In order to classify regions, the user has to “train” SPRING as to what pixels are what land use types. This is done in the Training

window accessed from the Classification window. (Image > Classification > Training). Here, the classes are named, assigned a color, created, and then target pixel groups are selected and assigned to the possible classes. In this analysis, several million pixels were assigned to the classifications in order to make sure the entire image was reclassified.

The image reclassification was finished in the “Classification” window (Image > Classification > Classification).



The north and south classifications were brought together as one with the Image > Mosaic menu function. Then the resulting reclassification for the whole island was exported as a \*.tif georeferenced image for use in ArcMap.

Please see Monskal et al.'s 2011 *Geospatial Canopy Cover Workshop*, if any further detail about SPRING segmentation and classification is desired. Again, the segmentation and classification processes here are a product of working through the workshop document, and summarized for this report.

#### *i-Tree.*

Two applications in the i-Tree suite were considered in this analysis, i-Tree Vue and i-Tree Canopy. Vue is the more in depth analysis application as it actually uses national averages of different forest metrics in order to give outputs that describe ecosystem services. This application uses data from the National Land Cover Database (NLCD), which is generated by the federal government and describes all the contiguous states in terms of 26 possible land cover types. The NLCD also has maps for the amounts of forest canopy cover (%) and impervious surfaces (%). The maps are at a 30 meter resolution, and are obviously not as detailed as the PSLC or NAIP datasets previously discussed.

i-Tree Vue requires all three of these inputs, land cover, canopy, and impervious, for the entire area of study. These data for the area of interest, San Juan Island, were downloaded from the Multi-Resolution Land Characteristics Consortium (MRLC) website: [www.mrlc.gov/viewerjs/](http://www.mrlc.gov/viewerjs/). This is a map view from which you can zoom to, and download data for an area. In this analysis,

SJI was zoomed into, and then the Data Download Tool was used to get the data after selecting the options: Land Cover 2006, Impervious Surface 2006, and Forest Canopy 2001.

These three datasets can be extracted in ArcMap to the same boundaries used for the previous SPRING and ArcMap analyses. This process ensured the exact same spatial extent for all images entered into Vue.

Enter these images in the three locations asked for at the beginning "NLCD Imagery" i-Tree Vue page. After loading the imagery into the application, under "Analysis Options," Vue has the option to make adjustments to the Canopy and Impervious Surface images based on research from 2010 that showed that the NLCD process in general underestimates these two percentage output images. Finally, the application runs for the analysis of carbon storage and sequestration, and air pollution removal. Each analysis presents an image of the study area's potential to handle carbon or pollution metrics, as well as a report of the pounds and possible dollar values as an ecosystem service the forest is providing.

The application also allows you to run a simple model where you can estimate the change of ecosystem services based on a decrease or increase of the forest canopy coverage for the study area. As the initial estimation by Vue was that the island has a forest canopy of 58.1% already, a model was run for a decrease to 50% canopy, as well as one run for an increase to 65% canopy.

The i-Tree Canopy application uses imagery directly accessed from Google Maps. In short, the user defines an area of interest, and then enters into the application the possible classifications for land use or land cover. The area of interest is best defined using an Esri shapefile to delineate boundaries. Then, the

software randomly generates a point x and y coordinate, zooms the display window into it on Google Maps satellite images, and the user picks what classification that point belongs to. This is done over and over again, until the user thinks there have been enough samples to get a good feel for the land use cover. The software advocates for 500 to 1,000 points to be sampled. The output is nothing more than a table showing the percentage of land use classes for the study area. This application is better suited for more urbanized areas than San Juan Island, and would be good at determining several urban land use possibilities within city limits.

There are several other i-Tree application available in the i-Tree 5.0 software suite. Eco, Streets, Species, Hydro, and Storm all perform different functions for estimating ecosystem services like carbon storage, stormwater runoff mitigation, and modeling change over time. However, they are considered out-of-scope for this reports since they all require data inputs other than remote sensing options. For instance, i-Tree Eco is a very powerful application to estimate many urban forest services, but it requires boots-on-the-ground survey and data collections on forested areas.

#### *Fusion.*

Fusion is a freeware application that was downloaded from the USDA Forest Service's Pacific Northwest Research Station website (<http://forsys.cfr.washington.edu/fusion/fusionlatest.html>). This site provides the installation for the software and also an example data set to use in extensive tutorials that are available from the Forest Service at this link:

<http://www.fs.fed.us/eng/rsac/fusion/ie5/index.html?dhtmlActivation=window>.

Although there was success at running through sample data in the Fusion application, there was not success in trying to incorporate our raw data in \*.las formatted files. There is little doubt after examining sample data and tutorial exercises that Fusion is a power application where the user can execute great control on the outputs and metrics attempted. However, for this analysis, we are compelled to leave the use of Fusion up to the very software savvy individual who can dedicate the appropriate large amounts of time to learning the software, practicing it, and working out and around the problems that may arise.

#### *ArcMap.*

Esri's ArcGIS suite is capable of delineating many outputs if public domain lidar data is available. The Puget Sound Lidar Consortium (PSLC) is an online source for such data for the Puget Sound area, but the coverage and resolution is not consistent for the entire region. Luckily, PSLC has posted the three foot resolution bare earth and top hit DEMs for all of San Juan County. PSLC also has links to raw point cloud data that these DEMs are derived from.

Download the PSLC DEMs and add them to a new geodatabase in ArcCatalog (i.e. SanJuanIslandLIDAR.gdb) on a drive with a lot of data storage available. This is the workspace for the whole analysis. Set the scratch workspace in Environment to be the same \*.gdb. This is a data storage space-heavy sequence of analysis. Maintain the original projection of the DEMs as the default for the entire process.

Within ArcMap, beginning with bare earth and top hit DEMs, one can derive the height of vegetation (and all structures), delineate individual trees as both polygons and XY points, and create rasters of trees per acre, average tree height per acre, and forest canopy percent coverage per acre. Above ground biomass (ABM) can be calculated also using the outputs for canopy cover and mean height. There are many steps to achieve these outputs. Model Builder is a utility inside the ArcGIS suite for linking tools and scripts to automate data processing. This is especially useful in this situation given the many steps required, and the desirability of a workflow process that can be repeated on past and future DEMs that become available.

Each Model step is graphically presented with detail in the Results section. Each Model in the Toolbox accepts plainly labeled “INPUT”s and derives “OUTPUT”s. Also, each Model gives a suggestion for the name of the “OUTPUT” feature class, and subsequently suggestions for names of “INPUT”s based on previous Model outputs. Some intermediate data are set as parameters in the Models and are simply numbered. The intermediates are saved for examination by the user if necessary for troubleshooting or simply if desired.

There is no reason why a user has to be stuck using an acre as the resolution for trees per area or forest percent per area. These models are set up to use 1 acre as the default values only. To change outputs to a different value, run the models as before, but change the parameters in this list:

Models 1 – 4. All remain the same. You do not have to re-run these.  
Model 5.

Cell size of output raster (1 acre is 208.7103 ft cell size)

*Change to any value. E.g. 1000 cell size will give you a cell area of 1 million square feet.*

Model 6a. No change, but you must re-run.

Model 6b.

Enter the same cell size as your template raster in 6a. (e.g.

TreesPerAcre is 208.7103 for 1 acre cells)

*Change to your chosen cell size.*

*E.g. 1000 again.*

Model 7.

Multiplier to new cell size: For an acre, enter 64 if 1m res. raster used, or 70 if 3 ft. res. raster used

*Follow the formula.*

(Your chosen cell size / Resolution of your input Vegetation Height raster in feet) round off to integer value

E.g. Model default uses the VegHeigh\_min15\_nonBuilding raster. This is a 1 m resolution because it was generated using the NAIP land use raster created in SPRING at Model 3. Resolution in feet: 1m = 3.28 ft

*Follow the formula.*

(acre / your res) , round off to integer

(208.7103 ft / 3.28 ft) = 63.63

Rounded off to 64

E.g. 2

*Follow the formula.*

(1000/ your res) , round off to integer

(1000 ft / 3.28 ft) = 304.87

Rounded off to 305

Area of an acre OUTPUT: 43560 square feet

*Change to the area of 1 pixel for your chosen cell size*

*E.g. if cell size is 1000, enter 1000000 in this parameter(1000\*1000)*

Model 8. No change, but you must re-run.

All the output rasters are now at your new cell size.

E.g. Trees per 1 mill. square feet.

Forest percents, and zonal statistics are automatically correct because they are based on internal Shape\_area metrics in the first place and cell size does not matter.

	Model Summaries	INPUTS	Suggested names of OUTPUTS
1	Create a Vegetation Height Raster	bare_earth top_hit	<u>VegHeight</u>
2	Delineate Individual Trees from <u>VegHeight</u> raster	<u>VegHeight</u>	<u>VegHeight_minXX</u> (XX = chosen min) <u>Tree_polygons</u> <u>Tree_points</u>
3	Remove False Positives (requires an Urban land use raster)	Land use raster (from SPRING) <u>Tree_points</u> <u>Tree_polygons</u> <u>VegHeight_minXX</u>	<u>Tree_polygons_nonBuilding</u> <u>Tree_points_nonBuilding</u> <u>VegHeight_minXX_nonBuilding</u>
4	Get Tree Heights	<u>Tree_points_nonBuilding</u> <u>VegHeight_minXX_nonBuilding</u>	<u>Tree_points_nonBuilding_heights</u>
5	Create Trees per Acre & Average Tree Height rasters	<u>Tree_points_nonBuilding_heights</u>	<u>TreesPerAcre</u> <u>AverageTreeHeightsPerAcre</u>
6a	Template Raster, and Dissolve Tree Polygons by Raster Cells	<u>TreesPerAcre</u> <u>Tree_polygons_nonBuilding</u>	<u>PolygonRasterCells</u> <u>ForestAreaByCell</u>
6b	Create Forest Canopy Cover Percent per Acre	<u>PolygonRasterCells</u> <u>ForestAreaByCell</u>	<u>ForestCanopyPercent</u>
7	Create Alternate Forest Canopy by Counting Pixels	<u>VegHeight_minXX_nonBuilding</u>	<u>ForestCanopyPercent_fromRasterCalc</u>
8	Estimate Carbon Storage with AGB Equation	<u>ForestCanopyPercent</u> <u>AverageTreeHeightsPerAcre</u>	<u>AboveGroundBiomass_carbonProxy</u> <u>SummarizeAboveGroundBiomass</u> (table)