Delta Wildlife 2022 Inventory Report

Summary

This report provides a summary of the CruiseBoost inventory of 3694 CRP enrolled properties in the Mississippi Delta and tributaries, completed as part of an ongoing partnership between NCX (formerly SilviaTerra) and Delta Wildlife. These properties are in addition to the 4952 we inventoried in the upper Mississippi Delta in 2019, and the project included additional field measurements to capture the greater geographic extent. These were combined with remote sensing data to estimate stocking for over 100,000 acres of forestland, providing an inventory of the entire area with far fewer plots than possible from traditional cruising. Key results are:

- For parcels that received inventory plots, the resulting CruiseBoost estimates of stocking are well aligned with the corresponding cruise data.

- The distribution of stocking in the uncruised parcels largely conforms with that of the cruised stands for the sampling strata.

- We observe some lower estimates in CruiseBoost results for uncruised stands classified as “high stocking” stands during the original design. This appears to be attributable to the original classifications being derived from coarser estimates of stocking for the area; we believe that the CruiseBoost estimates here are more accurate indicators of stocking than the original stratification.

- **Given broad agreement with the cruise data, as well as additional inference of ground conditions thanks to remote sensing information, we conclude that this inventory is of suitable quality to generate parcel reports, including wildlife habitat information, for landowners. These reports have been developed and will be delivered to all participating landowners by May 2022.**

Project scope

We have produced reports for 3694 unique Fields according to USDA FSA records.

Number of Farm Numbers included in Project	1025
Number of Unique Farm Tracts in Project	1193
Number of Unique Landowners in Project	885

Field work

Background and First Phase

The first phase of this project was conducted in 2019, and focused on properties in the Upper Mississippi Delta. We conducted a two-stage inventory to gather plot information, first stratifying all properties based on forest type and relative stocking (low, medium, high), then selecting individual stands for cruising. Forest type and stocking information for stratification and stand delineation was drawn from our Basemap dataset. We collected information on forest overstory as well as attributes related to forest health such as presence/absence of invasive species. These data were used to fit CruiseBoost models to generate the inventory layers, and to inform modeling of key wildlife species (see appendix A) for each property. The results were individual landowner reports for each property.

Second Phase

The second phase of this project expanded the original area with two sets of properties, using different analytical approaches:

- **Properties within the Mississippi Delta ecoregion** were inventoried using NCX's CruiseBoost model-assisted inventory, as in the first phase of the project conducted in 2019. We designed a sample meant to augment the 2019 plots, where weighting by forest type and relative stocking strata would remain balanced when the new stands were incorporated. This consisted of 433 additional plots in 64 fields. These were combined with the 1273 plots (177 fields) collected in the original project to create a training dataset for 2021.
- **Properties outside of the Mississippi Delta** were inventoried with NCX's Basemap dataset. Basemap is a 30x30m layer of forest inventory information, including stem counts by species and size, that was developed using USFS FIA data coupled with remote sensing datasets. It provides the same type of forest inventory information as our CruiseBoost approach, but does not include the locally collected plot data.

Core models

We modeled basal area and trees per acre summaries using multilevel models that include remote sensing predictors (i.e., satellite data) and assume a varying intercept based on estimated stocking level from the initial delineation. **R^2 for the basal area model was approximately 0.7, while the trees per acre model was 0.57.** Basemap exhibits similar model performance relative to FIA data. While these statistics indicate reasonable model fit, note that both processes include several analytical steps after raw model predictions are made, and estimates from the final treelists can differ. In general, we believe that assessing the performance of CruiseBoost and Basemap against stand summaries of the cruise is more indicative of actual predictive performance. See the "Stand-level performance" section for these results.

Population summaries

Predicted population estimates of basal area and trees per acre are closely aligned with the cruise means and well within the 90% confidence interval (Table 1). In addition to overall stocking levels, the diameter distributions of the cruise data and CruiseBoost are similar, though CruiseBoost does not capture the small number of trees >30"dbh in the cruise data (Figure 2). Given the young age of many of these stands, much of the standing volume is premerch or in the pulp size class (Table 2).

Table 1: Population comparison of basal area per acre and trees per acre between the original plot data and CruiseBoost output. Cruise C.I.s are reported at 90% confidence.

	Cruise	Cruise S.E.	CruiseBoost
Basal area (ft^2/acre)	58.6	53	56.3
Trees/acre	344	212	375

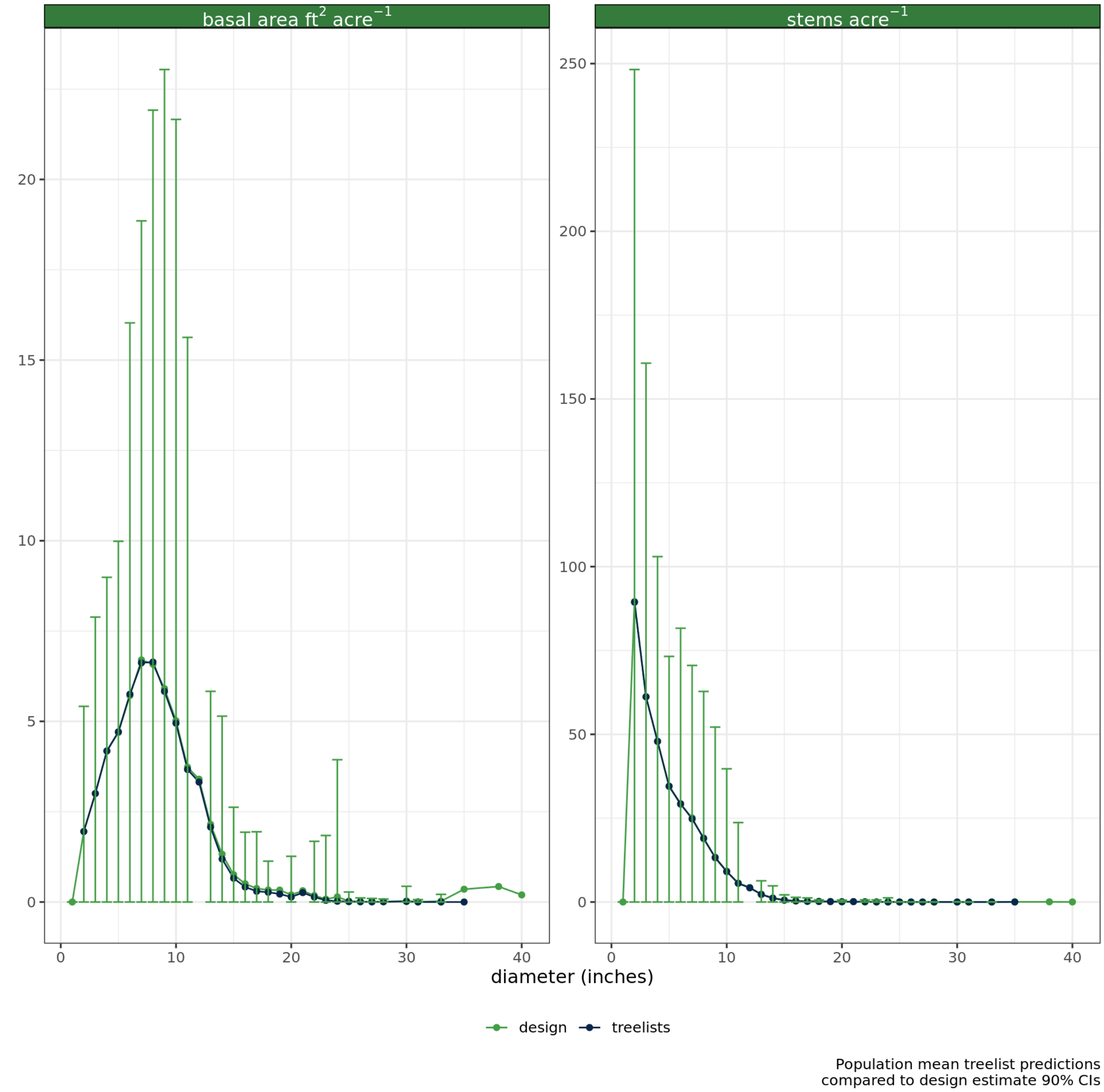


Figure 2: Population diameter distributions for the cruise data (design) and CruiseBoost output (treelist).

Examining trends of basal area by species indicates that commonly planted species such as Nuttall (Texas red) oak, cherrybark oak, water oak, and green ash are the most prevalent (Figure 3). CruiseBoost predicted less cherrybark oak and more Nuttall oak than observed in the cruise. Our species distributions indicate that cherrybark oak has a more southern distribution within the project area, and due to constraints on where we had permission to sample, the majority of the plots were in the northern end of the area of interest. Note that the the bulk of the 'other hardwoods' group in Figure 3 is composed of other oak, hickory, and tupelo species.

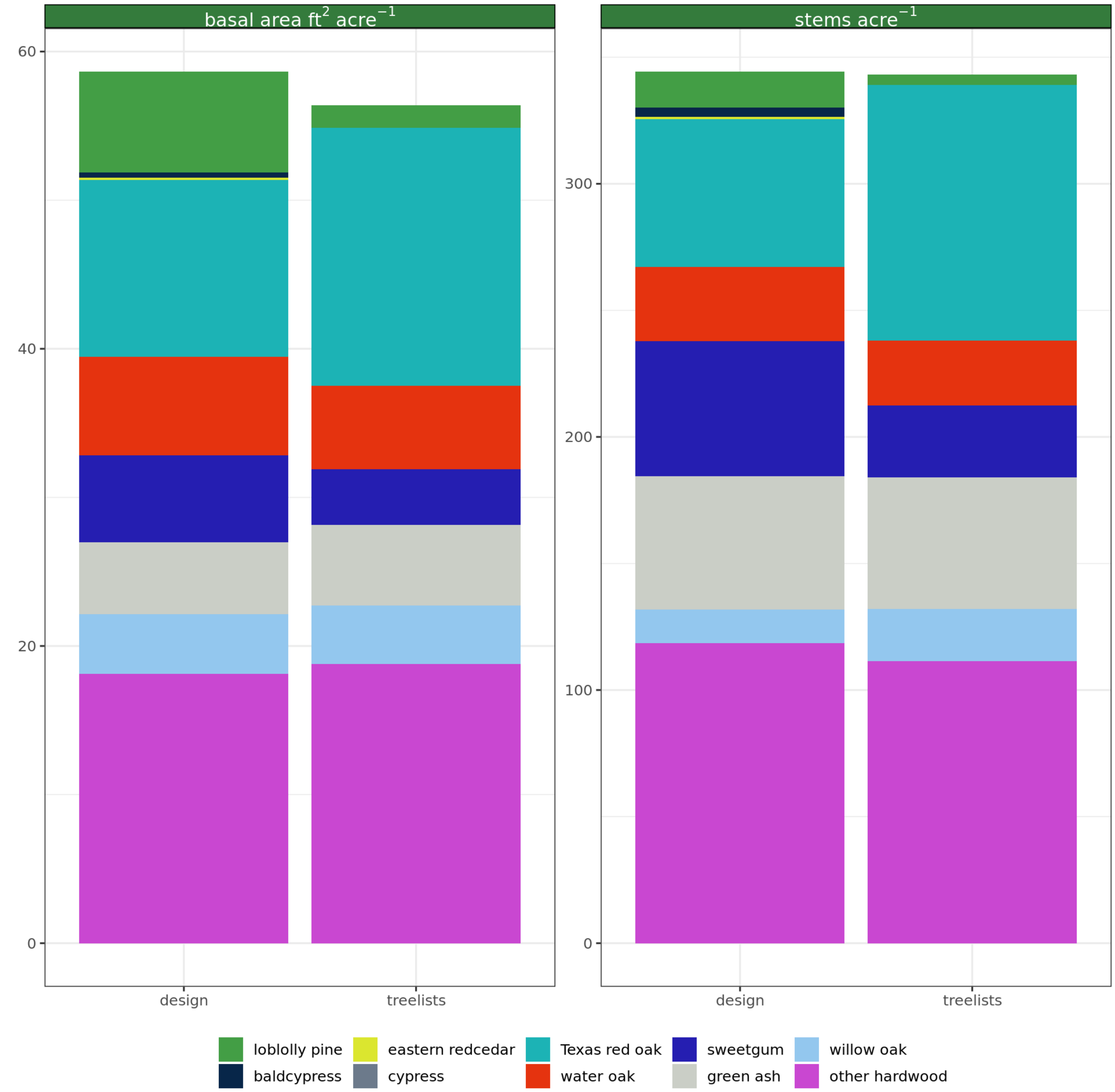


Figure 3: Comparison of basal area by species for the full population.

Heatmaps

CruiseBoost output is available for a grid of 30m pixels covering the project area, and rasterized "heatmaps" of stocking estimates provide a very effective way to visualize species composition and stocking across the area. We've provided two examples below of how these heatmaps reflect patterns visible on the landscape (Figures 5 and 6). Note that in the first image, CruiseBoost captures pattern wetlands with low stocking. In the second image, it successfully identifies roads, ponds, and landings.

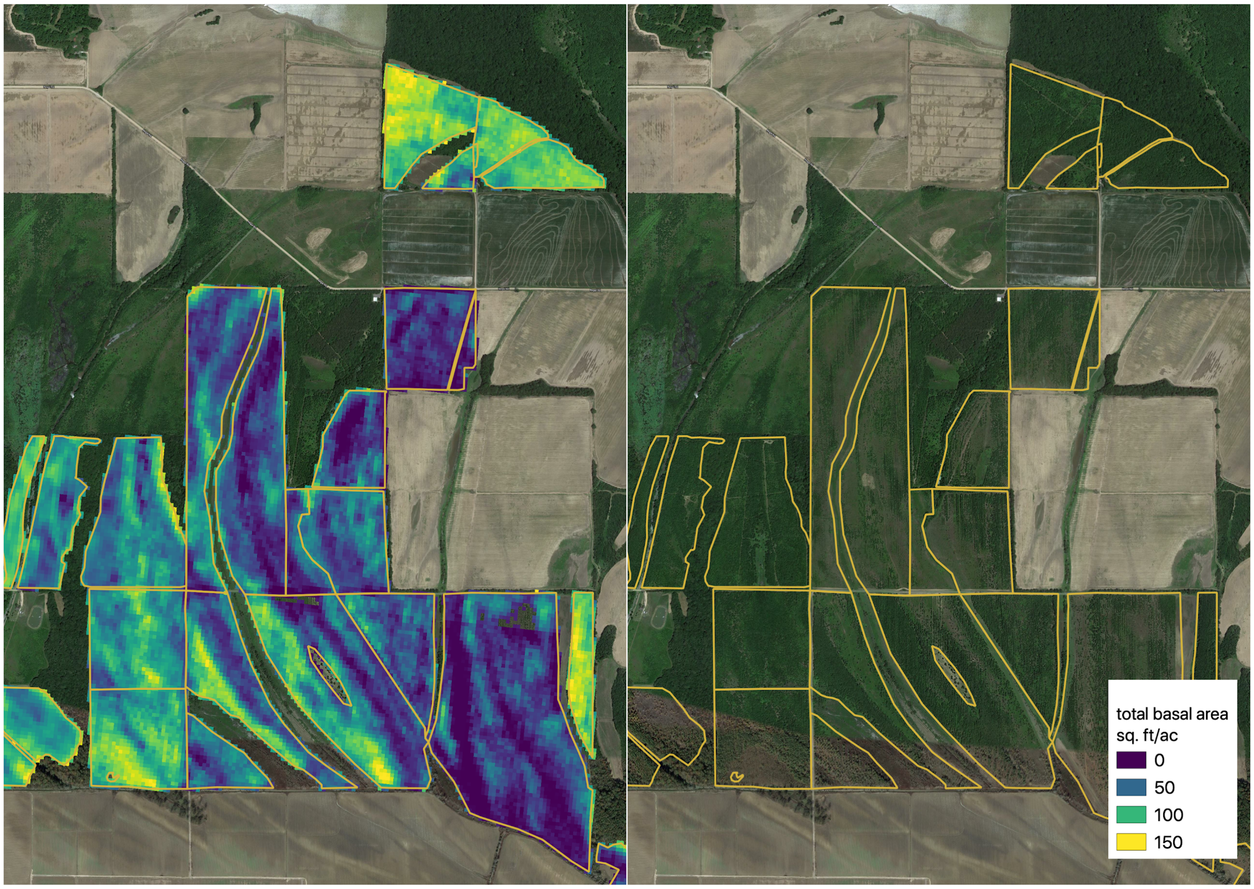


Figure 5. Visualization of total basal area for some parcels.

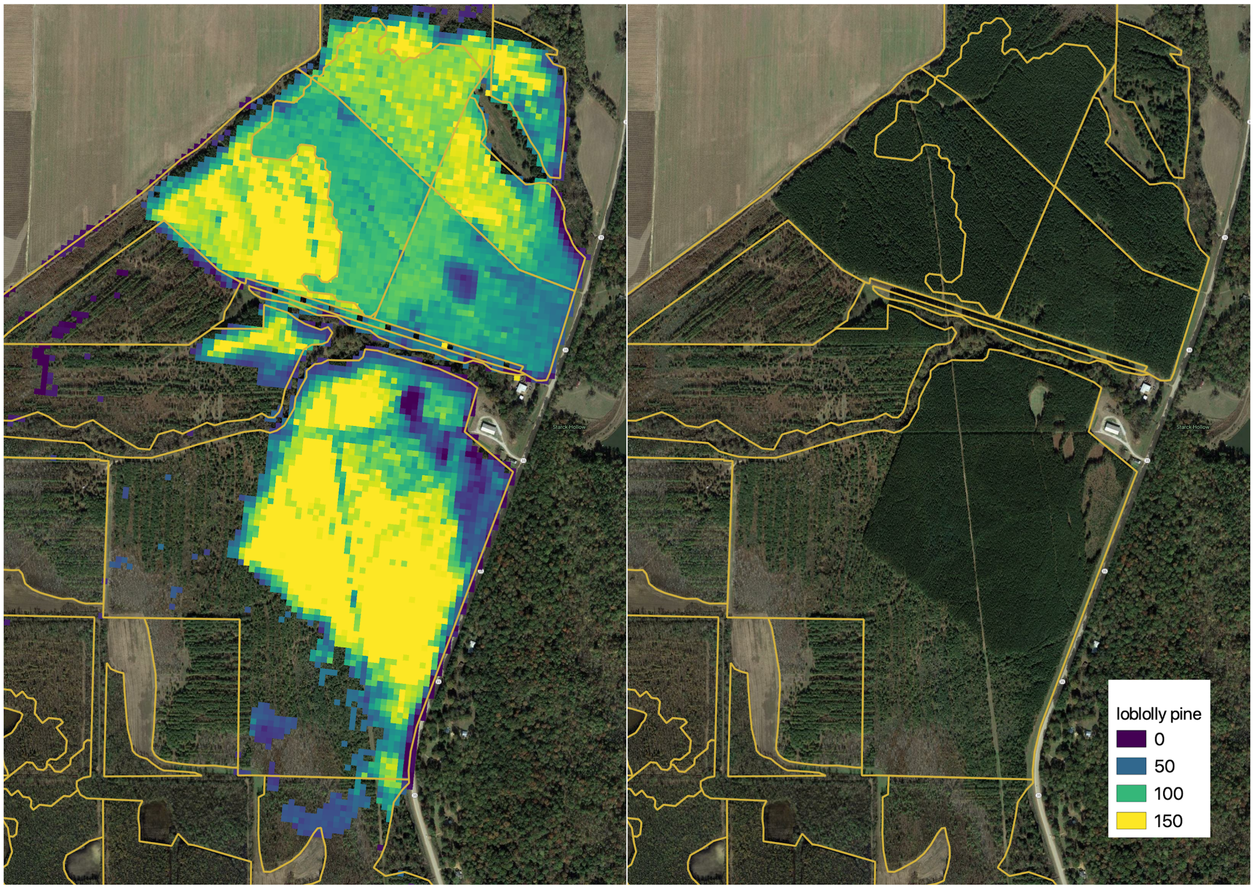


Figure 6. Visualization of loblolly pine basal area estimated for some parcels.

Total height models

We fit nonlinear (Chapman-Richards) functions to the height/diameter profile of each species. The exception was loblolly pine, where limited data led to a poor fit and we instead used a linear function. Total height predictions for the cruise data show that these models generally capture the observed height/diameter relationships, though they do miss some outlier predictions (>90 ft) in the 10-15” dbh class (Figure 10).

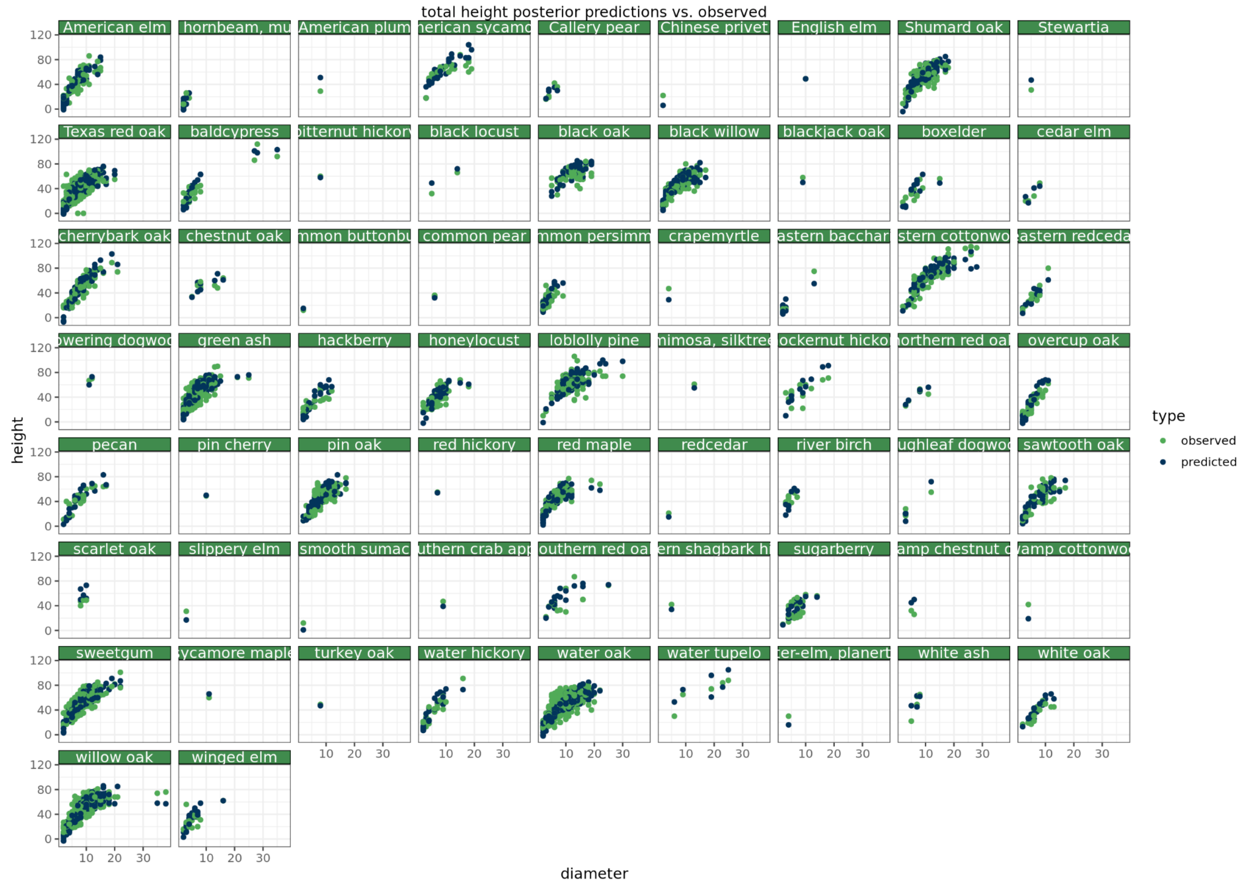


Figure 10: Predicted vs. observed total height for the cruise data.

Landowner property reports

The CruiseBoost inventory described here was used as the basis for producing custom landowner reports designed specifically for this project. These have information on forest inventory, including stocking levels and species composition, as well as future projections of timber value and habitat potential for key wildlife species. These reports were produced and delivered to all participating landowners via mail in April 2022.

For further information on the methods used to produce the report summaries, please refer to the Appendix A “Delta Wildlife landowner reports: Growth, volume, and wildlife habitat estimation”. Appendix B includes an example report for one property.

Supplementary Information

SilviaTerra's CruiseBoost Inventory Process: Overview

The CruiseBoost Process

Each SilviaTerra project is based on our CruiseBoost process for enhancing forest inventory data with auxiliary remote sensing information (Figure 1). The steps of the CruiseBoost process are as follows:

1. Collect field data.
2. Collect remote sensing information covering the entire area to be inventoried.
3. Pair field measurements with remote sensing data taken at the plot locations.
4. Develop remote-sensing assisted models based on these data.
5. Generate predictions for every pixel within stands using these models.
6. Develop stand-level estimates and/or treelists based on these predictions.

The result of CruiseBoost is a model-assisted inventory of cruised stands[1] that is **based on field measurements, but refined by pixel predictions where there is no plot coverage.** This approach **improves the resolution of information at the sub-stand level**, and is extended to **uncruised stands** to develop **model-based inventory assessments**. Appendix A contains a detailed description of the CruiseBoost methodology.

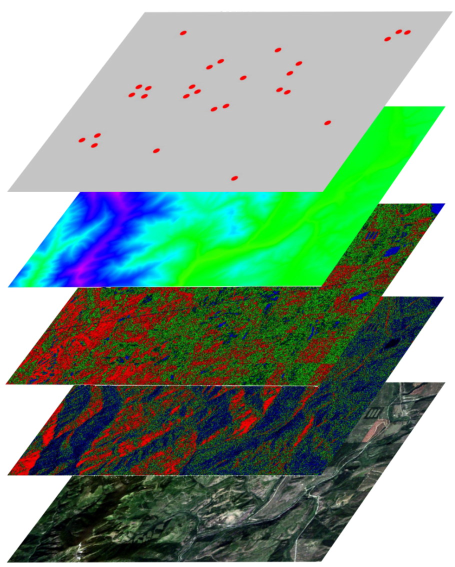


Figure 1: Visualization of a remote sensing "image stack" used by SilviaTerra to develop

[1] See: Särndal, C. -E., Swensson, B., & Wretman, J. 1992. Model assisted survey sampling.
And also
McRoberts, Ronald E.; Næsset, Erik; Gobakken, Terje. 2013. Inference for lidar-assisted estimation of forest growing stock volume. Remote Sensing of Environment. 128: 268-275.

CruiseBoost models. The top layer represents the sample plot locations.

Advantages of CruiseBoost over traditional inventory and other model-based approaches

A CruiseBoost analysis provides a richer set of information than a traditional cruise work up, but utilizes the inventory data to ensure model predictions reflect ground conditions where we have high confidence in the cruise (i.e., a stand with many inventory plots). This **model-assisted framework** allows us to efficiently detect "real" differences between model predictions and inventory data while avoiding the biases that may arise from models alone.

CruiseBoost efficiently pools the data from all of the cruises rather than analyzing stands in isolation, and as such presents several advantages over traditional inventory methods, including:

1. Plot data from one stand can be used to inform similar stands, leading to **more robust estimates in cruised stands** and **model-based inventory in similar uncruised stands.**
2. Our modeling approach naturally produces **rasterized heatmaps of stand stocking**, which are useful for harvest planning and/or stand condition assessment (Figure 2).

Additionally, given that it uses a model-assisted approach that is constrained by the inventory, CruiseBoost offers the following advantages over other predictive modeling approaches:

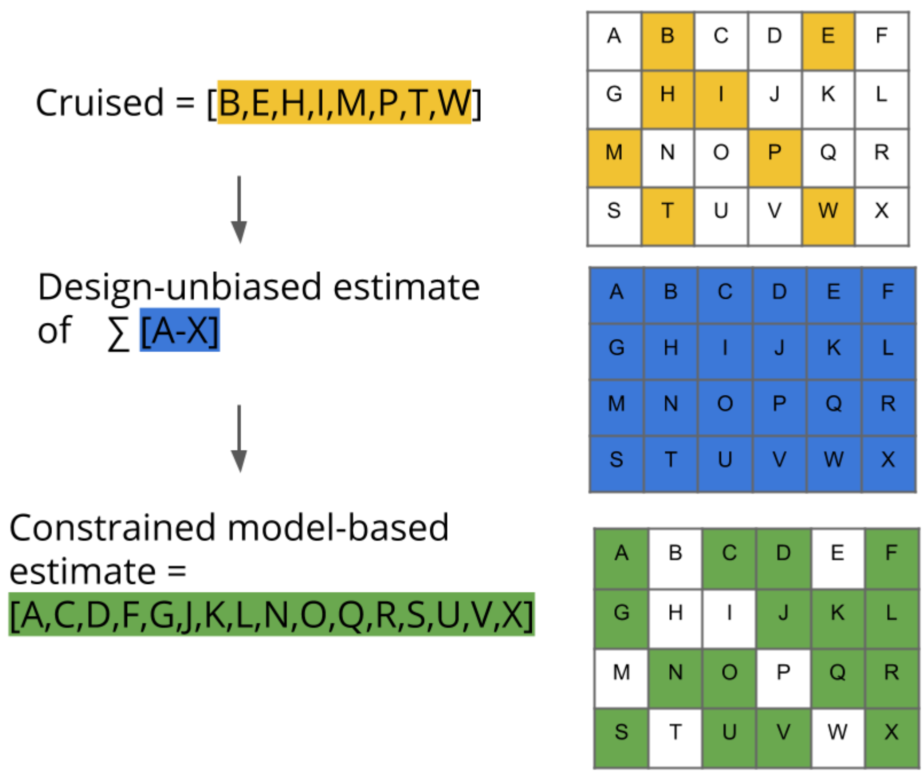
1. **Population estimates are constrained by the cruise**, ensuring top-level accuracy while still using sub-stand information to **increase stand-level precision**.
2. The CruiseBoost process allows for **automated rendering of treelists** that can be formatted to integrate with any volume estimation, growth modeling, etc. processes.

The standard set of CruiseBoost deliverables include stand summary tables and/or treelists for all stands, as well as heatmaps of the attributes of interest.

Balancing to a population-level number

A key component of SilviaTerra's CruiseBoost system is the incorporation of a design-unbiased estimate of stocking derived from a traditional cruise of the area of interest.   We focus specifically on the estimates of trees per acre and basal area for the area.

A two-stage sample, where plots were measured within selected stands, was installed across the property. A standard summary of that cruise will provide an unbiased estimate of the stocking for the full area - the mean of the cruised stands (shown in yellow below) in the sample is an estimate of the mean of the full population (shown in blue below). We use this information to evaluate and adjust the total estimate from the uncruised stands (shown in green below). We expect the average estimates for **all stands** to be approximately equal to the cruise-based average estimate from **all plots**, and the CruiseBoost system explicitly uses this information to balance the overall estimates to meet that top-level number. This ensures that the final result is in line with the cruise sample, and provides a 'check' on SilviaTerra's inventory product.



CruiseBoost methodology

Remote sensing datasets

The models fit in the CruiseBoost process utilize several remote sensing datasets, including:

- Sentinel multi-band satellite imagery
- Digital elevation models
- Aerial imagery
- Satellite radar data

Additionally, we are able to integrate additional remote sensing data such as LiDAR data where available.

The advantage of using remote sensing data as the main predictors in our models is that, since these datasets are available "wall to wall" across the project area, the fitted models can be used to make predictions **at locations where no inventory plots are present**. This allows SilviaTerra to provide additional information at the sub-stand level that cannot be derived from a traditional cruise, and to use inventory data to inform predictions for uncruised stands within the area of interest.

CruiseBoost core models

The core of CruiseBoost is predictive models of four attributes: (1) basal area per acre; (2) trees per acre; (3) species composition, expressed as a species importance score; and (4) diameter distribution. Standard predictors for all four models are a set of principal component scores derived from the remote sensing data inputs. Additionally, a SilviaTerra biometrician will evaluate stand-level metadata for potentially useful variables (i.e., site index), and incorporate these if preliminary analysis indicates they are likely to improve predictive performance.

Basal area per acre and trees per acre are both modeled using generalized linear models, typically with a log-normal distribution to increase normality and with all resulting predictions constrained to be positive. When stand-level categorical predictors are used (i.e., forest type) we extend the default formulation to a multi-level model.

Species importance is defined using the following equation:

$$\textit{Species Importance} = \frac{\frac{TPA\ of\ species}{Total\ TPA} + \frac{Basal\ area\ of\ species}{Total\ Basal\ Area}}{2}$$

Species importance for each project is modeled for individual species using random forest regression. Diameter distribution is also modeled using random forest regression, with plot-level cruise data expressed as relative scores for each diameter classes.

Prior to proceeding with prediction, a SilviaTerra biometrician undertakes a thorough evaluation of core model performance. This includes checking fit statistics, as well as cross validation tests of predictive performance where plot data from individual stands are successively held out as validation data. Once a set of suitable core models are obtained, they are used to generate raw predictions for all pixels across the study area.

Auxiliary models

Since the output of CruiseBoost is a treelist for each stand, SilviaTerra is able to model tree-level variables including total and merchantable height, product calls, and volume. Our standard approach for heights is to build a set of equations by comparing a suite of commonly used functional forms (for example, Chapman-Richards and Gompertz functions) to cruise data of each species. When there are few observations of a species available, we often query the US Forest Service Forest Inventory and Analysis (FIA) database for additional height records in the vicinity of the project area. Our volume estimates are based on a set of taper models, and we utilize a merchandising system that is capable of accepting custom specifications. Categorical variables such as grade are typically assigned proportionally based on species or diameter class, unless circumstances dictate that a good predictive model can be designed.

More so than our set of core models, the auxiliary models are frequently altered based on preliminary analysis of the cruise data and/or specific needs of a project. See the project-specific methodology section of your report for details on how these attributes were predicted, if auxiliary variables are part of the deliverables for your project.

Pixel predictions

Once the core models are fit, they are used to generate 'raw' predictions of all attributes for every pixel in the project area. These raw predictions consist of a mean prediction, used as the basis for our treelists, as well as assessments of pixel precision that we use both as constraints in our model-assisted inventory process and as the basis for assessing the precision of stand-level estimates of basal area and/or trees per acre.

Generating treelists

The 'tree-listing' process consists of two steps: (1) balancing the raw predictions; (2) generating pixel-level treelists and compiling these at the stand-scale. The balancing process utilizes an optimization approach to ensure that, at the top-level, the output treelists will be congruent with the population summaries from the cruise data. Implicit in this assumption is that the cruise is design unbiased, and therefore presents a reasonable estimate of the population mean. When this isn't the case, such as when cruise was conducted opportunistically, we may incorporate additional data or relax our assumptions about congruence.

Once the raw predictions are balanced, we use the final output (basal area per acre, trees per acre, species composition, and diameter distribution for each pixel) to generate an output treelist for each stand using SilviaTerra's patent-pending technology. These raw treelists can be converted into output format that interacts with other analytical systems, and are summarized to obtain final summaries at both the stand and population level. If auxiliary variables are part of the project, they are also predicted for every entry in the output treelist at this stage.

Validation and quality control

SilviaTerra biometricians conduct rigorous evaluation of output at several stages of the CruiseBoost process, including: (1) after fitting initial models; (2) after generating raw pixel predictions; (3) after generating treelists; and (4) before delivery of final output to the client.

The goals of our validation procedure are two-fold. First, since the foundation of CruiseBoost is rooted in traditional forest inventory, we check to ensure that output attributes (total basal area and trees per acre, trees by diameter class or species, etc.) aligns well with the cruise data at both the population and stand level. Where differences are detected we undertake an evaluation to determine if the CruiseBoost output is reliable (i.e., a stand was partially harvested and this portion received no plots), or if we need to make further adjustments to models and/or constraints.

Second, since CruiseBoost is a model-assisted inventory, we undertake thorough evaluation of model predictive performance to ensure that the predictive models we use are reliable. This is mainly through cross validation procedures, where portions of the data are withheld and predictive performance is evaluated against these plots. This procedure allows us to get a sense of how well the models do at predicting for stands where there are no plots. This is important to know, since estimates for uncruised stands are model-based.

Estimating precision of inventory estimates

We calculate two statistics to assess the precision of stand-level basal area per acre and trees per acre estimates:

1. A model-assisted standard error and confidence interval for cruised stands.
2. A posterior prediction uncertainty interval for both cruised and uncruised stands.

The former is based on equations of Särndal[2], and is similar to other confidence interval formulations in that it is based on the residual error between predicted and observed values.

We do this because the latter **accounts for error associated with our predictive models**, while the former **accounts for sampling and residual error only**. This is an important distinction, since the uncertainty interval will often be wider given that it directly accounts for additional error typically ignored by traditional inventory methods. SilviaTerra's biometrics staff can assist you in identifying which statistic makes the best sense for your project, as well as its correct interpretation.

Since a traditional model-assisted standard error requires plot observations to compute, we cannot apply it to model-based inventory for uncruised stands. In these cases, posterior prediction uncertainty intervals are derived from pixel-scale simulations of our attributes of interest, given the error of the predictive models and underlying data. In a sense, we generate a sample of simulated inventories' for a stand and estimate precision based on the range of potential BAPA or TPA values our model suggests. These can be expressed as quantile intervals (e.g., a 95% uncertainty interval) similar to confidence intervals.

These two statistics are similar, but do have some important differences. **Uncertainty intervals directly account for the error in the model, and therefore are sometimes wider than confidence intervals, which only consider the sampling error in the underlying data.** SilviaTerra's biometrics staff can assist you in identifying which statistic makes the best sense for your project, as well as its correct interpretation.

How does this compare to the standard deviation of a cruise?

The variance of a design-based sample (for example, the variance or standard deviation of 10 plots), can be interpreted in two different ways. An estimate of variance of basal area from plot data provides a sense of the heterogeneity of the stand itself - if plots have a large range of values, the stand is highly variable, and the variance is high. It also provides a sense of the precision of the mean - often people interpret a small confidence interval as showing a "better" estimate of the mean. Measuring more plots can lead to a smaller confidence interval, which contributes to this understanding.

[2] Särndal, C. -E., Swensson, B., & Wretman, J. 1992. Model assisted survey sampling.

The uncertainty interval provided with the CruiseBoost estimate of each stand should be interpreted as an estimate of **the precision of the mean for that stand** - it reflects the information provided to the models about pixels like the pixels in that stand, and how well the models perform in those pixels.

The uncertainty interval **does not** explicitly provide a sense of the **heterogeneity** of the stand. If there is a wide range of stocking within the stand, that will not automatically result in a large uncertainty interval.

Appendix A: NCX/Delta Wildlife project: Growth, volume, and wildlife habitat value projections

One of the deliverables of this project is to develop growth projections for individual landowner parcels, including projections of future stumpage and wildlife habitat value, that will be included in individual parcel reports. This document briefly summarizes the approach NCX used to get these projections.

Growth

Growth projections will be made for a 60 year time horizon for each of three different thinning scenarios: (1) free grown; (2) thinning from below to a target basal area based on the Goelz stocking diagram; (3) thinning of non-masting species to target basal area. All growth projections will be made with FVS. We used regionally appropriate defaults and set thinning targets to be consistent with standard silvicultural recommendations for forest types (mainly bottomland hardwoods, though a small number of upland pine and oak forests are included).

Volume and stumpage value

At each growth interval, volume is estimated for individual stems using taper equations and the merchandising rules established at the onset of the project. We calculated stumpage value based on a rate of $23.95/ton for pine sawtimber, $33.14/ton for hardwood sawtimber, and $10/ton for pine and hardwood pulpwood. These represent average numbers for the US south (http://www.timbermart-south.com/prices.html).

Wildlife habitat quality

One of the main goals of this project is to use CruiseBoost output on forest structure to quantify quality habitat for key wildlife (white-tailed deer, Wild Turkey, waterfowl, neotropical migrating songbirds). To accomplish this, we developed a set of 'habitat quality indices' (HQI) that map to CruiseBoost attributes and are based on conversations with regional experts as well as review of the literature on wildlife management in the Mississippi Delta.

- **White-tailed deer:** Based on consultation with Dr. Bronson Strickland and other members of the MSU deer lab, we ranked deer habitat based on total basal area and presence of mast producing species. Both of these variables influence forage availability for deer, with lower total basal area (< 50 ft^2/acre) being particularly important for supporting high quality herbaceous vegetation.
- **Wild Turkey:** We spoke with Adam Butler, Wild Turkey Program Coordinator with Mississippi's Department of Wildlife, Fisheries, and Parks. Based on his advice, we defined turkey habitat based on stand age (hardwood QMD) and presence of mast producing species.
- **Waterfowl:** We spoke with Dr. Orin Robinson, Research Scientist with the Cornell Lab of Ornithology, and conducted extensive literature review on forest management practices for waterfowl in the south. Since waterfowl are a broad group with varying ecologies, we focused mainly on food resources (presence of mast producing species), but also considered the prevalence of nesting sites (i.e., hardwood trees > 12" dbh) for Wood Duck.

- **Neotropical migrating birds:** This is another broad group, and as a result ‘quality habitat’ can be defined in many different ways. After discussions with Dr. Robinson, we chose to focus specifically on interior forest nesting birds. As a result the habitat quality index for this group is based on proportion of the total property in mature hardwood forest (hardwood QMD > 8”).

Appendix A: Habitat Quality Index rubrics for target wildlife species & groups

Individual HQIs are designed to fall between 0 and 5, and are mapped to one or more forest structural attributes that can be extracted from CruiseBoost output.

White-tailed deer
Deer HQI = ba Score + mast Score

Where:
baScore = 3 IF total basal area < 50 ft^2/acre,
2 IF 50-75 ft^2/acre,
1 IF 75-100 ft^2/acre,
0 IF > 100 ft^2/acre

mastScore = 2 IF masting species are 10% or more of total basal area,
1 IF 5-10% of total basal area,
0 IF <5% of total basal area

Wild Turkey
Turkey HQI = qmd Score + mast Score (as defined above)

Where:
qmd Score = 3 IF hardwood qmd >= 10 “,
2 IF 8-10”,
1 IF 6-8”,
0 IF < 6”

Waterfowl
Waterfowl HQI = mature hw Score + mast Score (as defined above)

Where:
mature hw score = 3 IF hardwood TPA over 16” dbh > 5,
2 IF 3-5,
1 IF 1-3,
0 IF < 1

Neotropical migrating birds

Songbird HQI = 5 IF proportion of property in mature forest (qmd >= 8”) > 90%,
4 IF 80-90%,
3 IF 70-80%,
2 IF 60-70%,
1 IF 50-60%,
0 IF < 50%