ACR IMPROVED FOREST MANAGEMENT METHODOLOGIES

TOOL FOR COMPARABLE PROPERTIES ANALYSIS

VERSION 1.1

September 2025

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ACR[SM]

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ABOUT ACR[SM]

ACR is a leading global carbon crediting program operating in regulated and voluntary carbon markets. Founded in 1996 as the first private voluntary greenhouse gas (GHG) registry in the world, ACR creates confidence in the integrity of carbon markets to catalyze transformational climate results. ACR ensures carbon credit quality through the development of environmentally rigorous, science-based standards and methodologies as well as oversight of GHG project verification, registration, and credit issuance and retirement reporting through its transparent registry system. ACR is governed by Environmental Resources Trust LLC, a wholly-owned nonprofit subsidiary of Winrock International.

Acknowledgements

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Acronyms

AGB	Aboveground biomass
DEM	Digital Elevation Model
ESA	European Space Agency
FIA	Forest Inventory and Analysis Program of the USDA Forest Service
GHG	Greenhouse gas
GIS	Geographic information system
GLAD	Global Land Analysis & Discovery
ID	Identifier
IFM	Improved forest management
LCMS	Landscape Change Monitoring System
NAIP	National Agricultural Imagery Program
NLCD	National Land Cover Database
SOP	Standard operating procedure
USDA	United States Department of Agriculture
USGS	United States Geological Survey

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1 Introduction

1.1 Summary

This tool, the *ACR IFM Methodologies Tool for Comparable Properties Analysis*, prescribes requirements for greenhouse gas (GHG) projects that use an ACR improved forest management (IFM) methodology and a comparable properties analysis to determine Harvest Intensity.

The comparable properties analysis is a systematic geospatial and statistical exercise that calculates Harvest Intensity for a given project on the basis of recently observed harvest rates occurring on similar properties in the region.

To conduct the comparable properties analysis, eligible comparable properties are identified through analysis of cadastral data (i.e., tax parcel boundaries) and eligibility criteria. Harvests are identified using remote sensing methods and data sources. Properties are stratified by forest cover type.

Eligible comparable properties are then evaluated for similarity to the project property using relevant site, biomass and forest type criteria, resulting in a narrowed list of most similar (or "matched") comparable properties. Matched properties are subject to outlier detection. Of the final matched comparable properties, one is selected for setting a stratum-specific Harvest Intensity constraint.

Harvest Intensities determined by a comparable property analysis are subject to dynamic evaluation using the *ACR IFM Methodologies Tool for Dynamic Evaluation of Baselines*.[1]

1.2 Applicability

This tool is required for GHG projects electing to substantiate Harvest Intensities using a comparable properties analysis, including projects validated under ACR IFM methodologies that explicitly refer to this tool and projects validated under other IFM methodologies that optionally apply the *ACR IFM Methodologies Tool for Dynamic Evaluation of Baselines*. This tool is not applicable to GHG projects validated under ACR's *IFM on Canadian Forestlands* methodology or the *IFM on Small Non-Industrial Private Forestlands* methodology.

[1] Available under the Program Resources section of the ACR website.

1.3 Process overview

Steps to apply this tool are summarized as follows:

Step 1 **Determine appropriate applicability of the tool.** ACR GHG projects validated under applicable IFM methodologies as outlined in section 1.2 must use this tool.

Step 2 **Define the lookback period.** The lookback period is the time period during which harvests are observed on comparable properties, which is relevant because Harvest Intensity is a harvest rate over time.

Step 3 **Define properties.** Properties are the basic unit to which the comparable properties analysis is applied. Properties must be geographically delineated both within the GHG project (i.e., project properties) and outside the GHG project (i.e., comparable properties). This step produces the geospatial layers for properties that serve as the inputs for Steps 3 and 4.

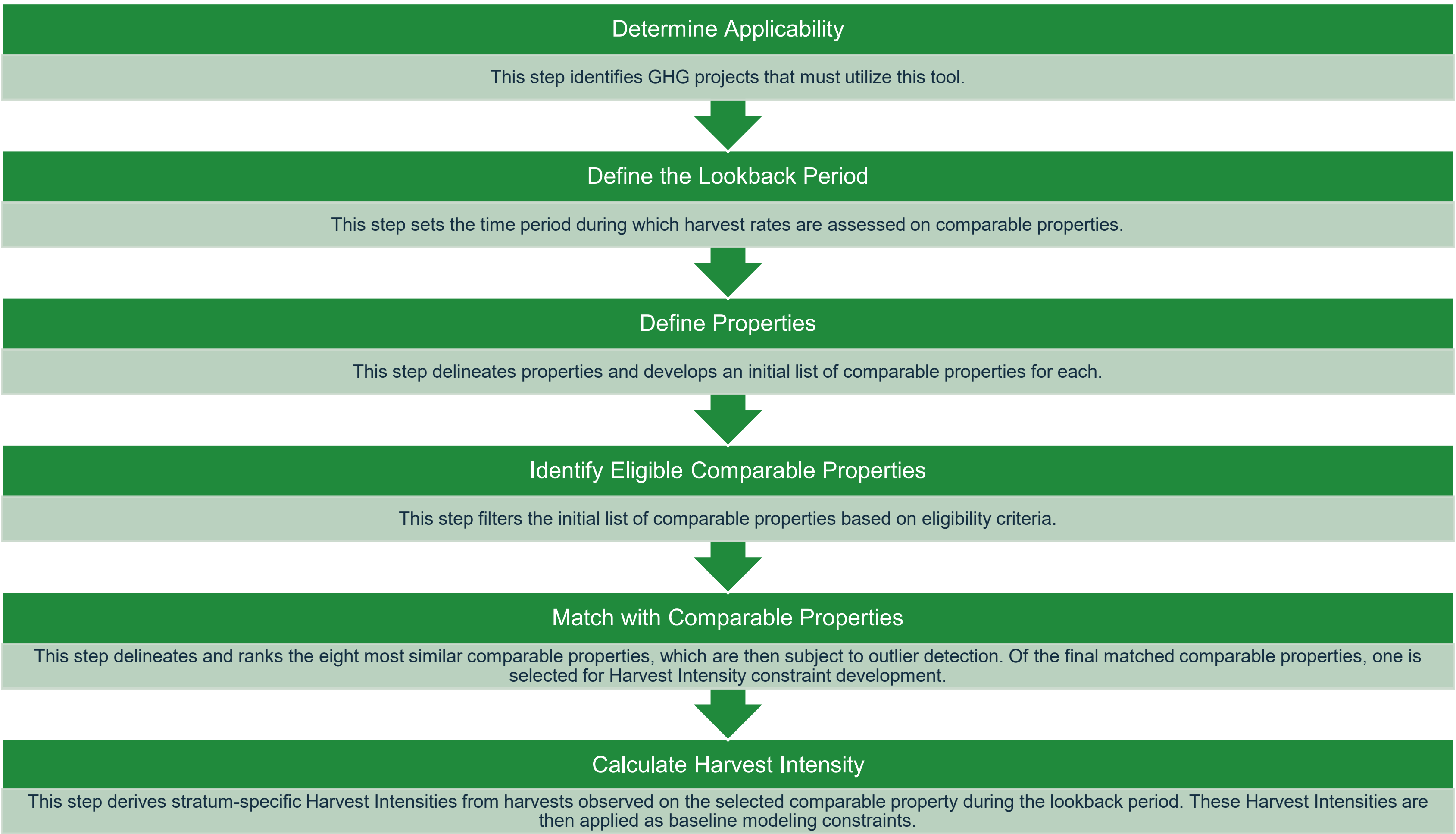
Step 4 **Identify eligible comparable properties.** Eligibility criteria are applied as filters on the list of properties that representing minimum qualifications for comparable properties. Eligibility criteria include proximity to the project property, geographic size relative to the project property, location within the same Ecological Region as the project property, similar timber ownership class as the project property, and harvest occurrence indicative of common practice forest management.

Step 5 **Match with comparable properties.** A statistical matching process is implemented to delineate and rank the eight most similar comparable properties on the basis of similarity criteria, including topography, aboveground biomass, canopy height distribution, and forest cover. The eight most similar (or matched) comparable properties are subject to outlier detection and any property that harvests in excess of common practice relative to the other matched properties is rejected. One of the final matched comparable properties is selected for stratum-specific Harvest Intensity constraint development.

Step 6 **Calculate Harvest Intensity.** A calculation framework is applied to derive Harvest Intensities from harvests observed on the selected comparable property during the lookback period. Harvest Intensities are derived for each forest cover stratum. They are then applied as baseline modeling constraints.

See also Figure 1:

Figure 1: Process overview



1.4 Companion Calculator

This document references the Comparable Properties Analysis Calculator[2] and Excel worksheets therein: the Eligible Comparable Properties worksheet, the Outlier Detection worksheet, and the Harvest Intensity Calculations worksheet. When conducting a comparable properties analysis, use and reporting of the companion calculator is required.

1.5 Example Demonstration

This tool and its companion calculator demonstrate an approved method to determine baseline Harvest Intensities using an example GHG project located in Georgia, USA. This region primarily consists of industrially managed pine plantations. The example property is approximately 21,000 acres and is owned by a private industrial timber company. The example project Start Date is in 2024.

Except for cadastral data, which can be unavailable to the public for free in certain geographies, and data from Google Earth Engine, this demonstration relies solely on publicly available data. It utilizes ArcGIS Pro, although other Geographic Information System (GIS) software may be used to attain equivalent results.

The following example demonstrates an approved method to perform a comparable properties analysis; other methods may be utilized if they adhere to the requirements of this tool.

[2] Found on this tool's website.

2 Defining the Lookback Period

Projects must first define a lookback period to evaluate Harvest Intensity on comparable properties. The lookback period must consist of at least 5 consecutive years within the previous 10 years, counting backwards from the most recent year for which data is readily available from the end of the Reporting Period. To ensure that recent market and management conditions are reflected, the lookback period may not exceed 10 years.

For example, if a remote sensing dataset does not publish its annual data until 2 years after collection and a GHG Project is verifying a Reporting Period ending 2025 (i.e., in which case the most recently available annual data is from 2023), the lookback period must include 2023 as its final year, and it must start at least 5 years prior (2019) and no more than 10 years prior (2014).

The example demonstration's lookback period has been defined as 5 years. 2023 is the year for which data is most recently available, so the lookback period starts in 2019 and ends after 2023.

3 Defining Properties

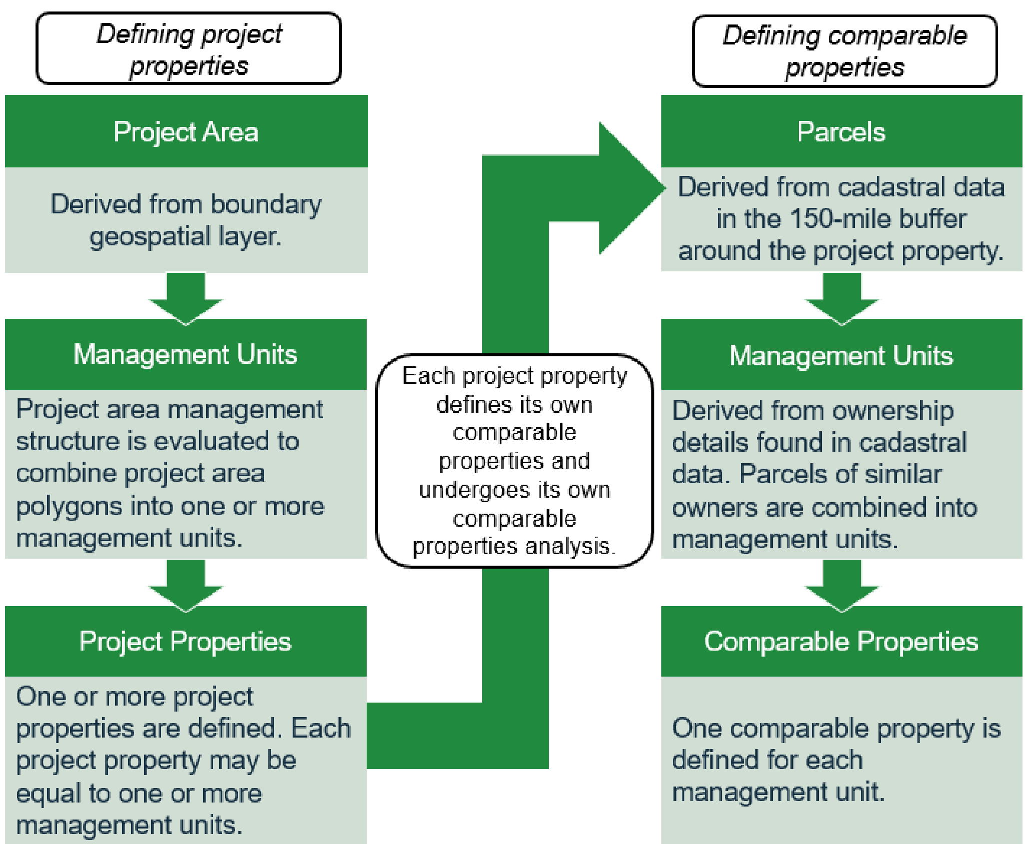
Properties are the basic unit to which the comparable properties analysis is applied. Properties must be defined (i.e., geographically delineated) both within the GHG project (i.e., project properties) and outside the GHG project (i.e., comparable properties).

Project properties are delineated from the project area boundary geospatial layer according to the number of distinct management units contained within the project area boundary (Section 3.1), which can be one or multiple.

Each project property requires its own comparable properties analysis for establishing baseline Harvest Intensities. As such, the process for defining project properties (Figure 2) determines how many comparable properties analyses must be conducted per GHG project.

The initial list of comparable properties is based on cadastral data (i.e., tax parcel boundaries) within a 150-mile buffer of the perimeter of each project property.

Figure 2: Process for defining project properties and comparable properties



GHG projects must develop and employ a standard operating procedure (SOP) to guide a systematic process for defining properties. This SOP must include two sets of detailed descriptions and logical rules for both the processes of defining project properties (Section 3.2) and comparable properties (Section 3.3). SOP's must be consistently applied such that a verifier may replicate both processes. Section 8.1 contains reporting and verification requirements in this regard.

3.1 Management units

A necessary first step in defining both project properties and comparable properties is to delineate management units.

A management unit is a discrete land area in which timber harvest decisions are considered to achieve management (e.g., revenue) goals. Management units are generally not individual stands but rather groups of stands.

Management units are at minimum defined by these characteristics:

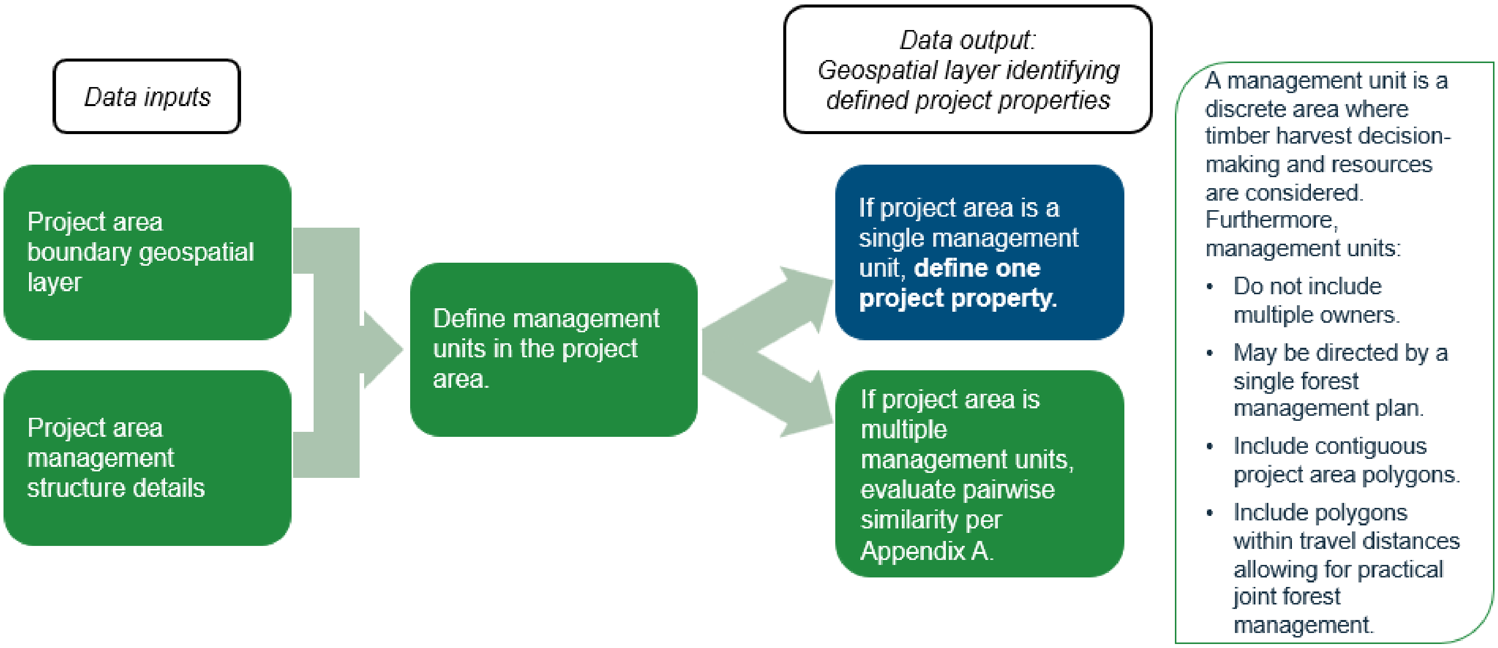
- A Management unit must not include areas belonging to multiple owners, unless their timber resources are jointly managed.
- Contiguous project area polygons (i.e., sharing a geographic boundary) must be combined into a single management unit, unless they demonstrably belong to distinct management units. Parcels separated by rights of way, watercourses, or small bodies of water are considered contiguous.
- Areas in a single management unit must be within travel distances allowing for practical joint forest management. At minimum, groups of polygons or parcels separated by more than 300 miles (aerial or road miles, dependent on the application of the proximity eligibility criteria; Section 4.1) must be considered separate mangement units; if the 150-mile buffers of any portions of the project property do not overlap, those portions must not be considered the same management unit.
- Forest management plans are useful but not necessarily conclusive indicators of distinct management units.

GIS polygons making up the project area boundary geospatial layer are assigned to management unit(s) and project properties according to Section 3.2.

3.2 Defining Project Properties

Figure 3 summarizes the process for defining project properties within the project area boundary. Please note that the expounded language found in section text supercedes the language found in Figures throughout.

Figure 3: Defining project properties



Delineating a project area's GIS polygons to management units must be verifiably informed by the management structure of the project participants and based on the definition and characteristics of a management unit in Section 3.1.

Once the project area polygons are delineated to management units the following requirements must be applied to guide the process of defining project properties:

- If the project area is composed of a single management unit, a single project property must be defined for the whole project area.
- If the project area is composed of multiple management units, the project shall evaluate pairwise similarity criteria to determine if and how they should be grouped into synthetic project properties.

This tool's example demonstration includes a single management unit, and thus a single project property is defined for the whole project area. For project areas with multiple management units, instructions for evaluating pairwise similarity and developing synthetic project properties are contained within Appendix A.

3.3 Defining Comparable Properties

To define comparable properties, a 150-mile buffer around the project property must be used to identify parcels from regional cadastral data (Section 4.1 contains additional details on proximity requirements). Acceptable sources for cadastral data include public agencies, academic resources, and commercial data providers. In some cases, individual counties and states will provide this data for free or upon request. In other cases, this data must be purchased. The full extent of cadastral data required by this analysis (i.e., all parcels within the 150-mile buffer) must be utilized. Portions of the required cadastral data may be excluded from consideration only with verifiable evidence of a good faith effort to obtain the data from multiple sources, including both relevant public agencies and commercial data providers. The cadastral data utilized must be a version created no earlier than 1 year before the Reporting Period end date; exceptions may be granted with advance written approval from ACR on the basis of unavailability of cadastral data within this recency threshold.

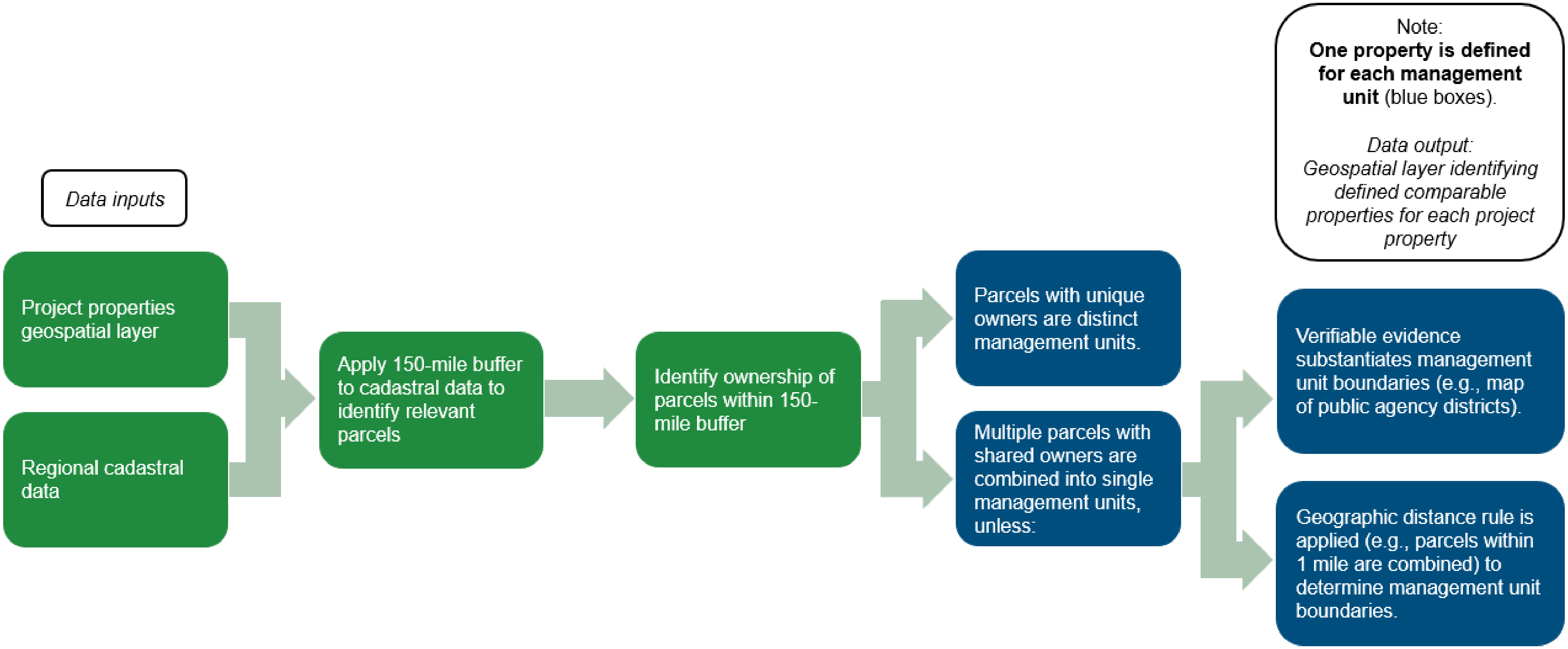
Parcels of comparable properties within the 150-mile buffer must then be combined into management units. This process may be conducted without internal knowledge of the management structure and objectives of all landowners in the region by using the following requirements to establish a verifiable and replicable parcel delineation process:

- One property is defined for each management unit (i.e., the list of properties is equal to the list of management units).
- Each parcel with a unique owner (or whose timber is managed by a unique entity) is considered a distinct management unit.
- Multiple parcels belonging to a single owner (or whose timber is managed by the same entity) must be combined into a single management unit, unless either of the following conditions exist:
    - Verifiable evidence (based on the definition and characteristics of a management unit; Section 3.1) is provided to substantiate the combination of a particular set of parcels into distinct management units. For public lands, boundaries of management units (also called districts or forests) may be publicly available. For private industrial lands, management units may be best defined by regional offices and lands under their purview, which may or may not be publicly available information.
    - Other geographically defined factors relevant to forest management, such as access (e.g., drive time) or legal jurisdiction, may be specified as appropriate for the region.

The result of defining comparable properties is a geospatial layer which includes all the properties to which the eligibility criteria (Section 4.1) shall be applied. Each defined project property (Section 3.2) must have its own distinct comparable properties geospatial layer.

Figure 4 summarizes the process for defining comparable properties.

Figure 4: Defining comparable properties



4 Identifying Eligible Comparable Properties

This section contains eligibility criteria for comparable properties and the data sources and methods required to determine and filter the list of eligible comparable properties. It follows steps taken to determine eligible comparable properties for the demonstration's example project.

The eligibility criteria represent bare minimum qualifications for comparability of properties, which are applied as filters on the initial list of comparable properties (i.e., the output of Section 3.3). If there are multiple project properties, each project property must identify its own set of eligible comparable properties.

Figure 5 summarizes the process for identifying eligible comparable properties.

Figure 5: Identifying eligible comparable properties

4.1 Eligibility Criteria

Projects must identify eligible comparable properties corresponding to each project property (Section 3), according to the specifications below. Eligible comparable properties must:

- **Harvest Occurrence**: Have an observed harvest during the lookback period and harvest at least 0.2% of their forestland per year.[3]
- **Geographic Size:** Contain forestland acreage meeting the following specifications:
  - If the project property is greater than or equal to 4,000 acres:
    - At least the greater of either: 25% of the forestland acreage of the project property, or 1,000 acres;
    - No greater than 250% of the forestland acreage of the project property.
  - If the project property is less than 4,000 acres:
    - At least the lesser of either: 75% of the forestland acreage of the project property, or 1,000 acres;
    - No greater than 250% of the forestland acreage of the project property.
  - Forestland acreage must be determined according to Section 4.1.6.4. To facilitate a less computationally demanding analysis, a pre-filtering step based on total acreage is recommended (Section 4.1.3), followed by a final filtering step based on forestland acreage after forest cover stratification (Section 4.1.7).
  - In regions with significant access constraints (e.g., interior Alaska), only forestland within a defined access threshold (e.g., within 2 aerial miles of an existing transportation network) should be considered when determining whether a comparable property meets the geographic size specifications. Projects seeking to implement this option must obtain advance written approval from ACR.
- **Ecological Region:** Be located within the same Ecological Region(s) as the project property.[4]
  - Project properties located in multiple Ecological Regions may consider properties located in either respective Ecological Region.

[3] Harvesting less than 0.2% of forestland per year is not considered indicative of common practice forest management.

[4] Ecological Regions are spatially defined areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources (Omernik, 1987; Omernik and Griffith, 2014). The Level II Ecological Region delineation is required. Spatial files are available at: https://www.epa.gov/eco-research/ecoregions-north-america

  - Properties in other Ecological Regions may be eligible when paired with verifiable evidence of a similar species and product mixture as the project property.[5]
  - Properties in other nations (e.g., Canada, Mexico) are deemed to be in different legal and economic environments, such that they are ineligible.
- **Ownership:** Be owned (or timber controlled) by a non-federal entity and by an entity of the same timber ownership class as the project property (Section 4.1.5).
  - Assignment of timber ownership classes must conform to the United States Forest Service (USFS) Forest Inventory and Analysis (FIA) owner classification (Table 1).
  - The project property or other properties owned (or timber controlled) by a participating entity but outside the project property may be eligible comparable properties.
  - If the timber rights of the project property were recently acquired (within less than 5 years of the project Start Date), the timber ownership class of the previous ownership may be assigned.
  - Properties owned by an entity of a timber ownership class with an equal or lesser discount rate (per Table 1) may be designated as eligible at the Project Proponent's discretion. If including properties within a lower discount rate class, all properties within that class must be included in the analysis.
  - Properties enrolled in a carbon project that incentivizes reduced harvesting may be designated as ineligible at the Project Proponent's discretion.
  - Properties whose ownership is unknown after good faith efforts to determine its ownership must be conservatively assigned to the Private Non-Industrial timber ownership class.
- **Proximity:** Be located within a 150-mile buffer of the perimeter of the project property[6] (Section 4.1.2).
  - Either aerial miles or road miles may be used.
  - If the Project Proponent can verifiably demonstrate the utilization of timber markets beyond the 150-mile buffer, by either the project property or another property in the same transportation network yet further from the timber market, the buffer may be expanded to match the distance to the furthest timber market utilized.

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[5] For example, forest type maps or other products showing similar timber types as the project property: https://www.arcgis.com/home/item.html?id=ec147f9df4664c83abc61ec6fa9b7736

[6] 150 miles is a generalized maximum hauling distance based on: Pokharel, R., & Latta, G. S. (2020). A network analysis to identify forest merchantability limitations across the United States. *Forest policy and economics, 116*, 102181. https://doi.org/10.1016/j.forpol.2020.102181

4.1.1 ADJUSTING ELIGIBILITY CRITERIA

The following steps establish a procedure to adjust eligibility criteria in the case that too few eligible comparable properties are identified. The following procedure must be implemented by projects that have identified fewer than eight eligible comparable properties, and it may be optionally implemented by projects that have identified fewer than 12 eligible comparable properties.

The following steps are required for adjusting eligibility criteria, when applicable. When proceeding to the next step in the sequence, the criteria adjusted in the previous step(s) must be reset to their default values in Section 4.1. For example, when first proceeding to Step 3, properties in adjacent Ecoregions are included using a 150-mile buffer around the project property and 250% maximum geographic size threshold. If fewer than eight (or optionally 12) eligible comparable properties are identified, Steps 1 and 2 must be applied in sequence while including properties in adjacent Ecoregions. Only after the conditions for proceeding onto the next step are satisfied for all preceding steps (e.g., 300-mile buffer, 300% geographic size threshold, and adjacent Ecoregions) may the next step in the sequence be applied.

Step 1 **Expand the buffer around the project property.** The buffer must be expanded in 50-mile increments. After each expansion, the project must determine whether a sufficient number of eligible comparable properties (i.e., at least 8 and no more than 12) can be identified. If 12 or more such properties have been identified, the eligibility expansion process shall end. This process must be repeated at least up to a 300-mile buffer before proceeding onto the next step, and it may be repeated up to a 500-mile buffer total.

Step 2 **Expand the maximum geographic size threshold.** The threshold must be expanded in 50% increments. After each expansion, the project must determine whether a sufficient number of eligible comparable properties (i.e., at least 8 and no more than 12) can be identified. If 12 or more such properties have been identified, the eligibility expansion process shall end. The maximum geographic size threshold must be expanded to 300% before proceeding onto the next step, and it may be expanded up to 400% of the geographic size of the project property total.

Step 3 **Include properties in adjacent Ecoregions.** Only properties in directly adjacent Ecoregions (i.e., Ecoregions sharing a geographic boundary with the Ecoregion(s) where the project property is located) may be included. At least one adjacent Ecoregion with properties within the buffer must be included (if available) before proceeding onto the next step. This step may not be applied if already justifying the inclusion of properties in other Ecological Regions with verifiable evidence of the similar species and product mixture as the project property, per Section 4.1 above.

Step 4 **Include properties of different timber ownership classes.** When determining which properties of different timber ownership classes to include for potential eligibility, both closeness of the assigned discount rates and conservatism must be considered. The project must determine whether a sufficient number of eligible comparable properties (i.e., at least 8 and no more than 12) has been identified after each of the following expansion rules have been applied. If 12 or more such properties have been identified, the eligibility expansion process shall end. If the project's identified ownership (Section 4.1.5) is either Private Non-Industrial or Tribal, properties of the same discount rate yet different timber ownership class must be included first. Next, properties of a timber ownership class with a discount rate one percent less than the project's discount rate are included. Next, properties of a timber ownership class with a discount rate one percent more than the project's discount rate are included. If the project has still not identified enough eligible comparable properties, properties of a timber ownership class with a discount rate two percent less than the project's discount rate are included, and so forth.

The following sections describe the process of applying filters on the initial layer of eligible comparable properties (Section 3.3) to determine a final list of eligible comparable properties.

4.1.2 PROXIMITY

The proximity eligibility criterion requires that a 150-mile buffer of the perimeter of the project property be applied. Proximity is first considered when determining which cadastral data is required for defining comparable properties (Section 3.3). Therefore, this step may be redundant if the 150-mile buffer has already been applied to generate the initial layer of comparable properties. Whether applied during the comparable property definition process or the eligibility criteria process, the following is an approved method to filter by proximity using road miles:

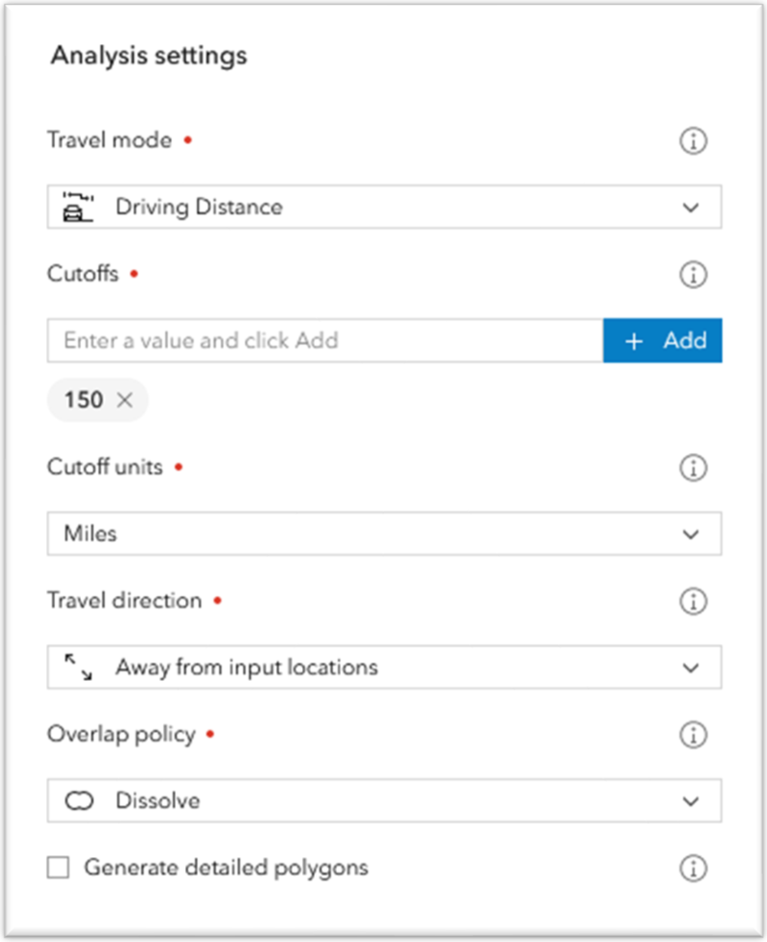
Step 1 Transform the project property polygon into a line shapefile using the Polygon to Line tool. Then create points along the project boundary using the Generate Points Along Lines tool. The distance between points may be set to 3,000 feet to balance accuracy of boundary representation with sufficient quantity of point data.

If the project boundary point shapefile has too many points, the Generate Travel Areas tool can run slowly. To improve performance, points in the inner part of the boundary may safely be eliminated, because the travel areas for inner points will be absorbed by the travel areas for more external points, thus reducing redundancies.

Step 2 Share the output layer as a web layer to upload it to ArcGIS Online.

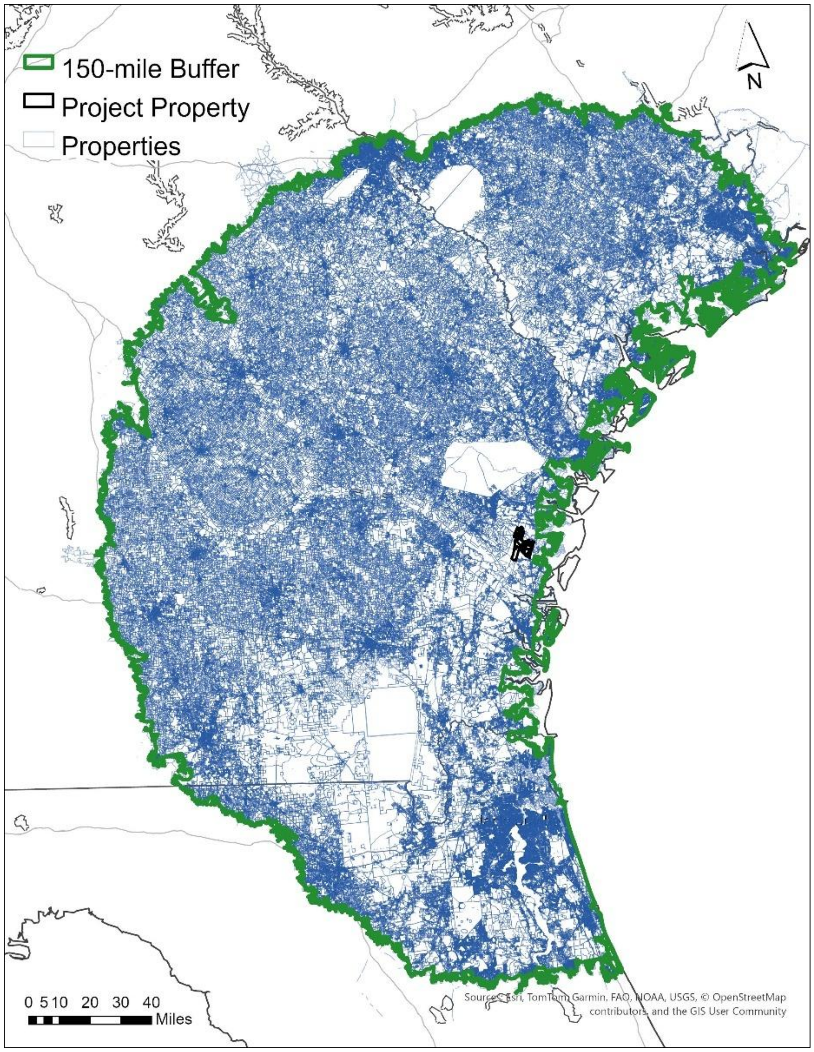
Step 3 Use the Generate Travel Areas tool and select "Driving Distance" as the travel mode with a cutoff of 150 miles. Travel direction should be "away from input locations," and the overlap policy "Dissolve" (Figure 6). The output will be called the Buffer layer.

Figure 6: ArcGIS Online Generate Travel Areas tool



Step 4 Load the Buffer layer in ArcGIS Pro and intersect it with the comparable properties layer (Section 3.3) to select all the properties within a 150-road mile buffer of the perimeter of the project property. The output layer should contain only properties intersecting with the buffer, and it will be referred to as the Properties layer (Figure 7).

Figure 7: Comparable properties filtered by 150-road mile buffer



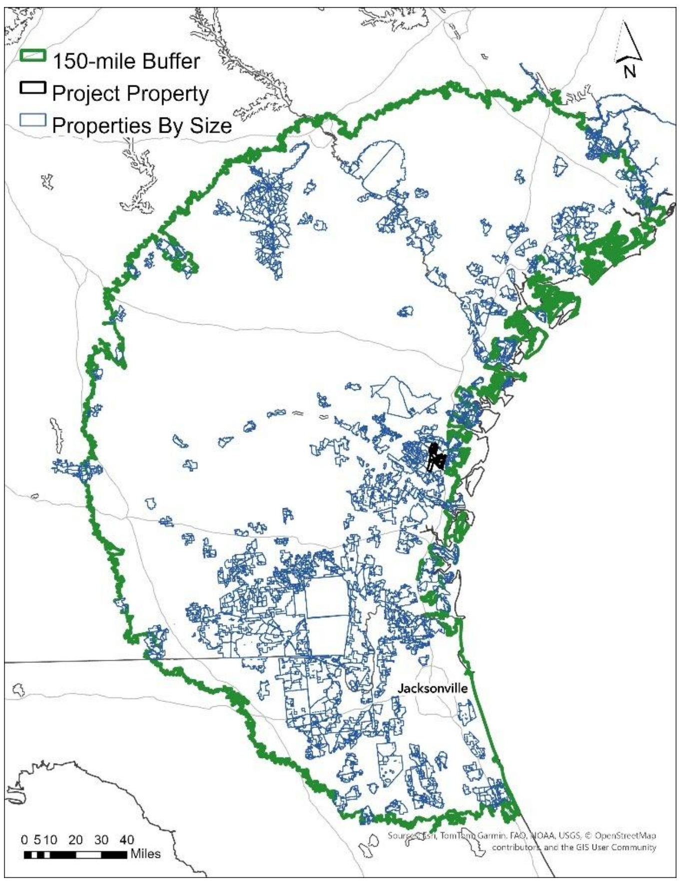
4.1.3 PREFILTERING FOR GEOGRAPHIC SIZE

To facilitate a less computationally demanding analysis, an optional prefiltering step on comparable properties is recommended based on total acreage. While forestland acreage is not available until forest cover stratification has been completed (Section 4.1.6.4), total acreage may be used to remove properties smaller than 25% of the total acreage of the project property, thus reducing the number of properties for the proceeding analysis steps. Prefiltering by total acreage may be performed as follows:

Step 1 Calculate the total acreage of all properties in the Properties layer using the Calculate Geometry tool.

Step 2 Select all properties from the Properties layer with total acreage meeting the minimum geographic size requirement (25%) using the Select by Attribute tool. In the example demonstration, total acreage must be greater than 5,236.79 acres. Create a new layer using the Make Layer From Selected Features tool. Make sure to keep a unique identifier (ID) for each property. The output layer will be referred to as the Properties By Size layer (Figure 8).

Figure 8: Comparable properties filtered by 150-road mile buffer and geographic size



4.1.4 ECOLOGICAL REGION

Eligible comparable properties must be located within the same Ecological Region(s)[7] as the project property. The following steps may be used to filter the Properties By Size layer by Ecological Region:

[7] https://www.epa.gov/eco-research/ecoregions-north-america

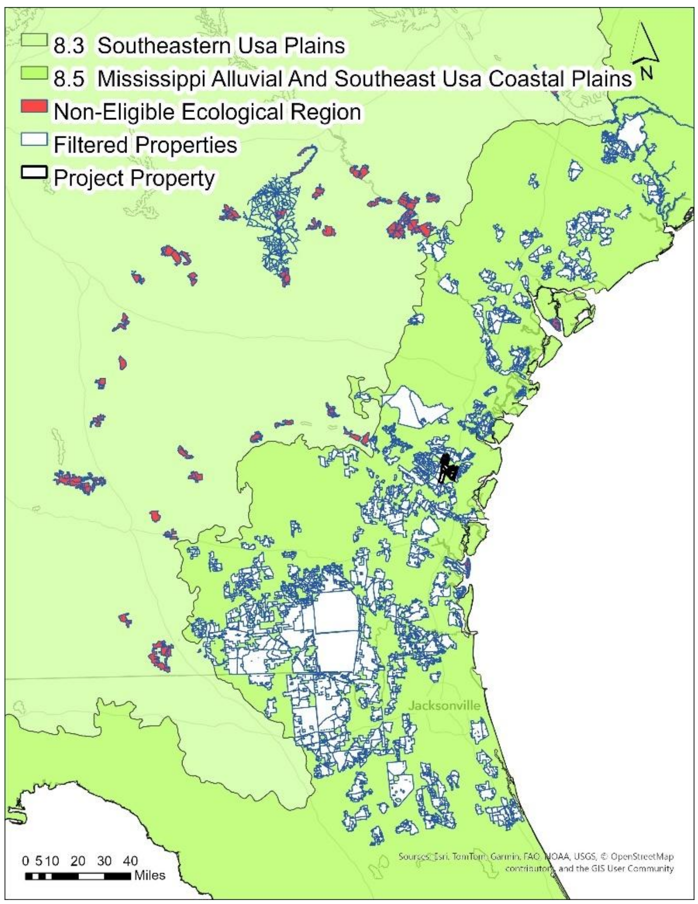
Step 1 Add the EPA's Ecological Regions of North America Level 2 data from ArcGIS Online.

Step 2 Select the Ecological Region in which the project property is located.

Step 3 Use the Select by Location tool to select all the properties intersecting with the selected Ecological Region.

Step 4 Create a new layer that contains the selected properties within the same Ecological Region as the project property. The output layer will be referred to as the Filtered Properties layer (Figure 9).

Figure 9: Comparable properties filtered by 150-road mile buffer, geographic size, and Ecological Region



4.1.5 OWNERSHIP

Eligible comparable properties must be owned by a non-federal entity and by an entity of the same timber ownership class as the project property. Filtering by ownership may be performed as follows:

Step 1 Obtain ownership data for all properties in the Filtered Properties layer and assign them to timber ownership classes (Table 1 below). Timber ownership classification must correspond to the USFS FIA owner classes.[8] Ownership data may be provided in the cadastral data layer or can be identified as belonging to timber ownership classes using public business registries and other online resources. Properties whose ownership is unknown after good faith efforts to determine its ownership can be assumed to be in the Private Non-Industrial timber ownership class.

Table 1: Discount Rates for Net Present Value Determinations by U.S. Forestland Timber Ownership Classes

TIMBER OWNERSHIP CLASS	CORRESPONDING FIA OWNER CLASS VALUE	ANNUAL DISCOUNT RATE
Private Industrial	41	6%
Private Non-Industrial	43, 45	5%
Tribal	44	5%
Non-Federal Public	31, 32, 33	4%
Non-Governmental Organization	42	3%

Step 2 Select all properties of the same timber ownership class as the project property. Section 4.1 provides further guidelines for instances when too few comparable properties of the same ownership class are available (e.g., timber ownership classes of equal or lesser discount rates at the Project Proponent's discretion, etc.).

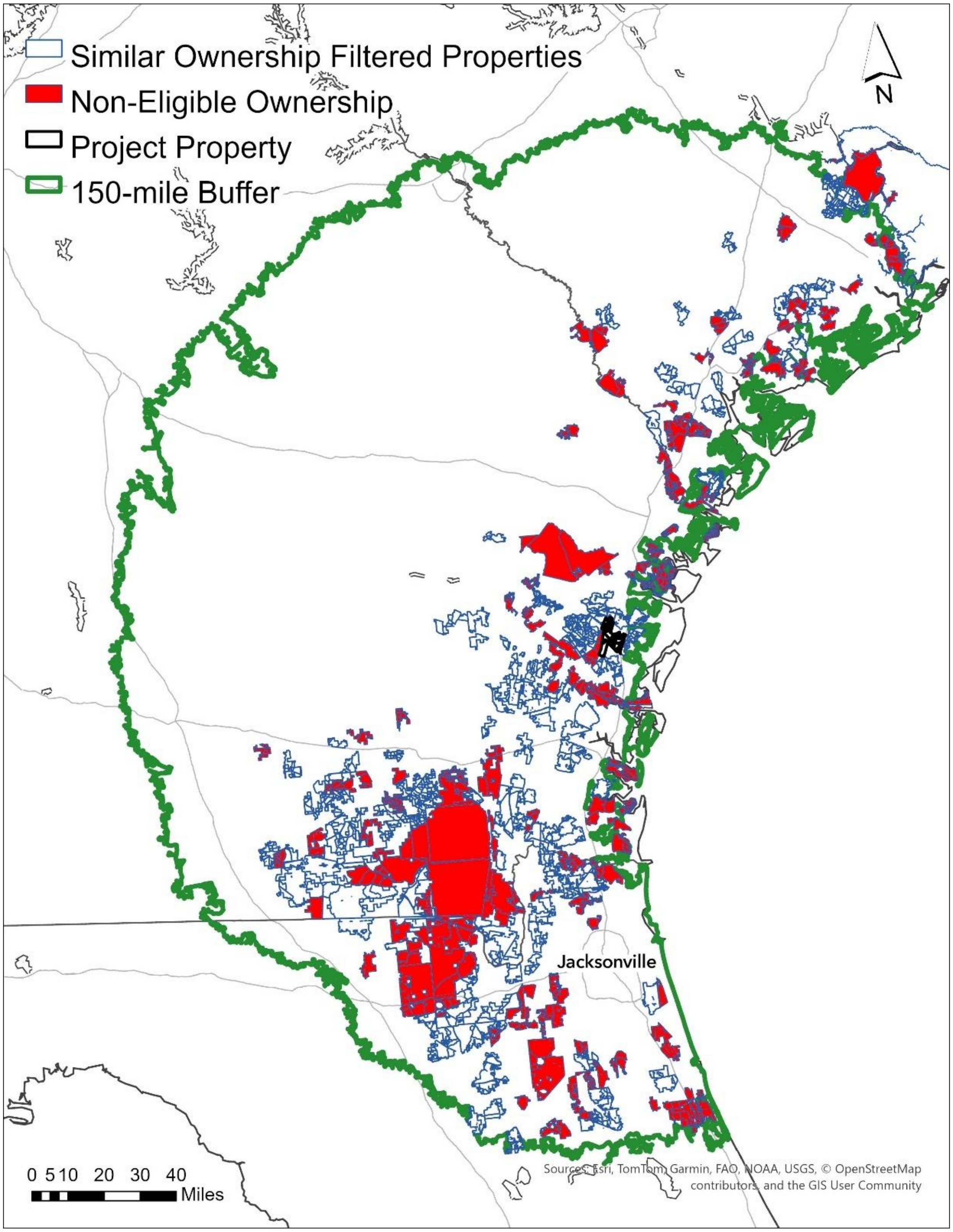
Step 3 Create a new layer with the selected properties, which will be referred to as the Similar Ownership Filtered Properties layer (Figure 10).

Step 4 Replace the project property's polygon(s) (derived from the cadastral data) in the Similar Ownership Filtered Properties layer with the project property polygon derived from the project area boundary geospatial layer, since this is the most up-to-date boundary for that property. To do so, select all the polygons that overlay with the project property and press delete. Join the Similar Ownership Filtered Properties layer with the project

[8] See section 2.5.7 of the following document for descriptions of FIA owner classes:

U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis National Program. (2023) Forest Inventory and Analysis national core field guide, volume I: Field data collection procedures for phase 2 plots, version 9.3. https://www.fs.usda.gov/research/understory/nationwide-forest-inventory-field-guide property polygon using the Merge tool. If applying a synthetic project property (Section 3.2.1), skip this Step.

Figure 10: Comparable properties filtered by 150-road mile buffer, geographic size, Ecological Region, and ownership



4.1.6 HARVEST OCCURRENCE

Eligible comparable properties must have an observed harvest during the lookback period and harvest at least 0.2% of their forestland per year (Section 4.1). In addition to identifying eligible comparable properties, harvest identification is also a key input in the calculation of Harvest Intensity (Section 6). This process involves first identifying areas of forest loss, then removing areas of natural disturbance, and lastly removing forest loss areas smaller than a minimum mapping unit.

The following sections describe the steps taken for this tool's example demonstration using approved default datasets and methods (i.e., GLAD and LCMS). However, other datasets and methods may be utilized. To utilize other models for identifying forest loss, they must be tested and approved for use according to Section 7.

A single method and data source (or set of data sources) for detecting forest loss must be used for the entirety of the lookback period. Regardless of the forest loss model used, areas of natural disturbance must be removed from the forest loss areas, and safeguards for salvage harvests must be implemented (Section 4.1.6.2).

4.1.6.1 Forest Loss Identification

This example demonstration's method combines the Global Land Analysis & Discovery (GLAD) forest loss and the Landscape Change Monitoring System (LCMS) annual change datasets to leverage each dataset's distinct approach to forest loss detection. Both datasets are publicly available and updated annually, and they may be used in conjunction as an approved method to identify forest loss.

Alternatively, the LCMS annual change dataset, filtered for Tree Removal and Other Loss, may be used independently (i.e., without GLAD) as an approved method to identify forest loss. If applying this method, there is no need to remove areas of natural disturbance, and the relevant steps found in Section 4.1.6.2 may be skipped accordingly.

An approved method to identify forest loss is as follows:

Step 1 Download the most recent GLAD forest loss (lossyear) layer. If multiple tiles are required, combine them into a single layer using the Mosaic to Raster tool.

Step 2 Download the LCMS annual change layers for each year during the defined lookback period. In this example, LCMS data from the years 2019 to 2023 is downloaded.

Step 3 Add the GLAD layer and the LCMS layers to the map. Project both layers to the same projection and snap layers to one another using the Project Raster tool. In this example, the LCMS layers are snapped to the GLAD layer.

Step 4 Create a buffer around the Similar Ownership Filtered Properties layer of at least the pixel size of the raster layers. In this example, a 30-meter buffer is created. This layer will be referred to as the 30-m Buffered Properties layer.

Step 5 Clip the GLAD forest loss and LCMS annual change layers raster using the 30-m Buffered Properties layer. Clipping the raster data using a buffered layer avoids missing pixels intersecting with the boundary. The LCMS layers created during this step will be referred to as the LCMS Change *Year* layers (*Year* should be replaced with the relevant year for each LCMS annual change layer) and will be used in Section 4.1.6.2.

Step 6 Select forest loss data in the GLAD layer only from years during the lookback period using the Extract by Attribute tool. In this example, GLAD data from the years 2019 to 2023 is selected. To aid in the selection of annual data, the following table may be used as a reference (Table 2):

Table 2: Global Land Analysis & Database values and their equivalent years, 2019 to 2023

YEAR	GLAD VALUE
2019	19
2020	20
2021	21
2022	22
2023	23

Step 7 Select the data in the earliest LCMS annual change layer that is attributed to Tree Removal (9) and Other Loss (13) using the Extract by Attribute tool. Repeat this step for each LCMS layer.

Step 8 Convert the GLAD and LCMS raster layers (from Steps 6 and 7, respectively) into polygons using the Raster to Polygon tool, choosing to not simplify polygons.

Step 9 In each LCMS layer, make the "gridcode" column equal to the year of the respective LCMS annual change layer for all objects using the Field Calculator tool. This maintains the year of forest loss data so the LCMS layers may be merged with the GLAD layer.

Step 10 Merge the GLAD forest loss polygons and the LCMS forest loss polygons into a single layer.

Step 9 Dissolve the layer using the field "gridcode" (raster value) to dissolve all polygons by database and year of forest loss. This will be referred to as the Forest Loss layer.

4.1.6.2 Natural Disturbance Removal

Next, areas of natural disturbance must be removed from the Forest Loss layer. The types of natural disturbance may vary by region, but all projects must make efforts to identify and remove areas impacted by natural disturbances.

The following steps demonstrate an approved method for removing areas impacted by natural disturbance using the LCMS annual change dataset. If using the LCMS annual change dataset filtered for Tree Removal and Other Loss independently (i.e., without GLAD) to identify forest loss, this section is not appliable as natural disturbance areas are already excluded per Section 4.1.6.1. Other reputable and verifiable datasets and sources for determining areas impacted by natural disturbances may be used.

Step 1 Select all polygons from the Forest Loss layer with a GLAD value equal to the first year in the lookback period (e.g., "gridcode" equals 19 for 2019). Since the LCMS data included in the Forest Loss layer was filtered to non-natural disturbances (Step 7 of Section 4.1.6.1), only the GLAD data included in the Forest Loss layer could be due to a natural disturbance.

Step 2 Create a new layer using the Make Layer From Selected Features tool. This layer will be referred to as the GLAD Forest Loss *Year* layer (e.g., GLAD Forest Loss 2019 layer). Repeat Steps 1 and 2 for each year during the lookback period.

Step 3 Select the data in the earliest LCMS Change *Year* layer (created in Step 5, Section 4.1.6.1) that is attributed to natural disturbance using the Extract by Attribute tool. The following LCMS classes should be extracted: Wind (1); Hurricane (2); Snow or Ice Transition (3); Desiccation (4); Inundation (5); Prescribed Fire (6); Wildfire (7); Defoliation (10); Southern Pine Beetle (11); and Insect, Disease, and Drought Stress (12). Repeat this step for each LCMS Change *Year* layer.

Step 4 Convert the extracted LCMS raster layers into polygons using the Raster to Polygon tool, choosing to not simplify polygons. These will be referred to as the Natural Disturbances *Year* layers (e.g., Natural Disturbances 2019 layer).

Step 5 Remove all areas in the GLAD Forest Loss *Year* layers that overlap with the Natural Disturbances *Year* layers of the corresponding year using the Erase tool. The output is a layer that contains GLAD forest loss data not due to natural disturbances occurring in that year. In this example, all areas in the Natural Disturbances 2019 layer are removed from the GLAD Forest Loss 2019 layer using the Erase tool, resulting in GLAD forest loss data not due to natural disturbances in 2019; this is repeated for each year during the lookback period.

Step 6 Select all polygons in the Forest Loss layer which originated from the GLAD dataset, as identified using the values corresponding to years (Table 2; e.g., 19, 20, 21, 22, and 23) using the Select by Attribute tool. Press delete to remove them. Merge the resulting Forest Loss layer with the layers containing GLAD forest loss data not due to natural disturbance occurring during the lookback period.

Areas of natural disturbance may be subject to salvage harvests which may go undetected as forest loss and therefore not inform the calculation of Harvest Intensity. Salvage harvests are operationally expensive[9] and may displace harvests on the landscape which would otherwise inform the calculation of Harvest Intensity. Projects may optionally apply adjustments to estimate areas of undetected salvage harvests for properties where they are verifiably demonstrated to occur.

To do so, projects must first identify properties subject to salvage harvests using timestamped high-resolution imagery (>50-centimeter to ≤ 2-meter resolution), such as the high-resolution imagery available on Google Earth Pro. If an area is subject to salvage harvests, it should have been previously identified as an area of natural disturbance (i.e., included in the Natural Disturbances *Year* layers created in Step 4 above). The imagery after salvage operations should show new skids, landings, or other signs or tracks of machinery associated with harvesting operations, with reduced evidence of natural disturbance damage (e.g., fallen trees removed). The visual indicators of salvage harvests will vary by region and type of natural disturbance. See Figure 11 for an example.

[9] Iranparast Bodaghi, A., Nikooy, M., Naghdi, R., Venanzi, R., Latterini, F., Tavankar, F., & Picchio, R. (2018). Ground-based extraction on salvage logging in two high forests: A productivity and cost analysis. *Forests*, *9*(12), 729. https://doi.org/10.3390/f9120729

Figure 11: Google Earth Pro imagery before (upper left) and after (upper right) hurricane damage, and after (lower) salvage harvests

If any areas of visually identified salvage harvests do not overlap with the Forest Loss layer, a salvage harvest adjustment may be made for that property. Precise geospatial locations need not be determined, but rather a simple proportion may be applied. 20% of the total area of the relevant natural disturbance(s) (i.e., the LCMS Change *Year* layer for the relevant year, filtered for the relevant LCMS class or classes) per forest cover stratum may be assumed to be salvage harvested in the year immediately following the relevant natural disturbance. This results in adjusted harvest acreages per forest cover stratum for that property, which equals the sum of each stratum's harvested acreage detected according to the procedures of this tool (Section 4.1.6) and the proportional salvage harvest adjustment.

This salvage harvest adjustment may only be applied after similarity matching (Section 5.2) to one of the matched properties. The property is then subjected to outlier detection (Section 5.3) using its adjusted percentage forestland acreage harvested. If all the areas of visually identified salvage harvests overlap with the Forest Loss layer, no adjustments for undetected salvage harvests may be applied for that property.

Regardless of whether salvage harvest adjustments are applied, efforts must be made to identify properties subject to salvage harvests to limit the inclusion of excessive salvage harvesting in the calculation of Harvest Intensity. Salvage harvests are implemented in response to natural disturbances generally affecting discrete areas,[10] and large-scale salvage harvests occurring on comparable properties may not be representative of an IFM baseline's alternative harvest scenario in the absence of the GHG project. As such, a safeguard to limit Harvest Intensity is required for properties subject to salvage harvests, to be applied after similarity matching (Section 5.2). Matched properties must be visually inspected using high-resolution imagery as described above. Any matched property that includes a visually identified salvage harvest is limited to a maximum of 10% forest cover stratum area harvested per year (inclusive of both adjustments for undetected salvage harvests and detected harvests) for all years during the lookback period. If salvage harvests are identified, a geospatial layer that generally locates (i.e., with a point and not a polygon) all identified salvage harvests must be provided for verification.

4.1.6.3 Minimum Mapping Unit

Projects may apply a minimum mapping unit, below which areas of forest loss are likely to be due to detection errors or slivers remaining after erasing areas of natural disturbance, neither of which may inform the calculation of Harvest Intensity.

If using the approved methods of this tool's example demonstration, the minimum mapping unit shall be 1 acre, and all areas less than 1 acre must be removed from the Forest Loss layer. If using another model tested and approved for use per Section 7, a minimum mapping unit may be determined by the project. Projects choosing to either not apply a minimum mapping unit or to apply a minimum mapping unit less than 1 acre must substantiate their choice with verifiable evidence of precise forest loss detection at the proposed threshold. Partial pixels must be excluded.

Given the spatial resolution of the GLAD and LCMS datasets, forest loss due to harvests may appear as disaggregated pixels, some of which may fall below the minimum mapping unit. This may be especially true for partial harvests (i.e., thinning). To avoid removing these harvested areas, polygons within 300 feet may be aggregated into multipart polygons before determining their size and whether they exceed the minimum mapping unit. The following steps demonstrate an approved method to apply the minimum mapping unit in this context.

Step 1 Clip the Forest Loss layer to the Similar Ownership Filtered Properties layer.

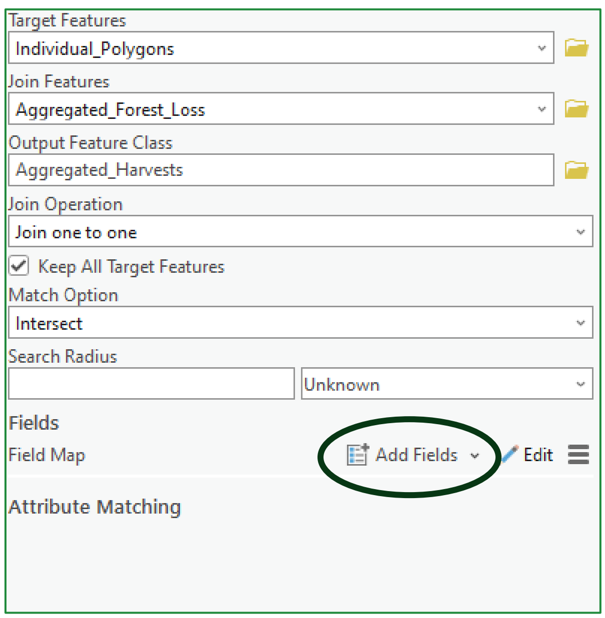
[10] Russell, M. B., Kilgore, M. A., & Blinn, C. R. (2017). Characterizing timber salvage operations on public forests in Minnesota and Wisconsin, USA. *International Journal of Forest Engineering*, *28*(1), 66-72. https://doi.org/10.1080/14942119.2017.1291064

Step 2 Disaggregate all the polygons using the Multipart to Singlepart tool. The output layer will be referred to as the Individual Polygons layer.

Step 3 Aggregate the Individual Polygons layer using the Aggregate Polygons tool. The Aggregation Distance should be 300 feet and the Aggregate Field should be "gridcode". The output layer will be referred to as the Aggregated Forest Loss layer.

Step 4 Give each polygon in the Individual Polygons layer the ID of their associated polygon in the Aggregated Forest Loss layer using the Spatial Join tool. This groups the disaggregated harvest polygons without adding new area to connect them. If the Aggregated Forest Loss layer's ID field is not available in the Spatial Join tool's fields section, it should be added (Figure 12). The output layer will be referred to as the Aggregated Harvests layer.

Figure 12: Adding a field in the Spatial Join tool

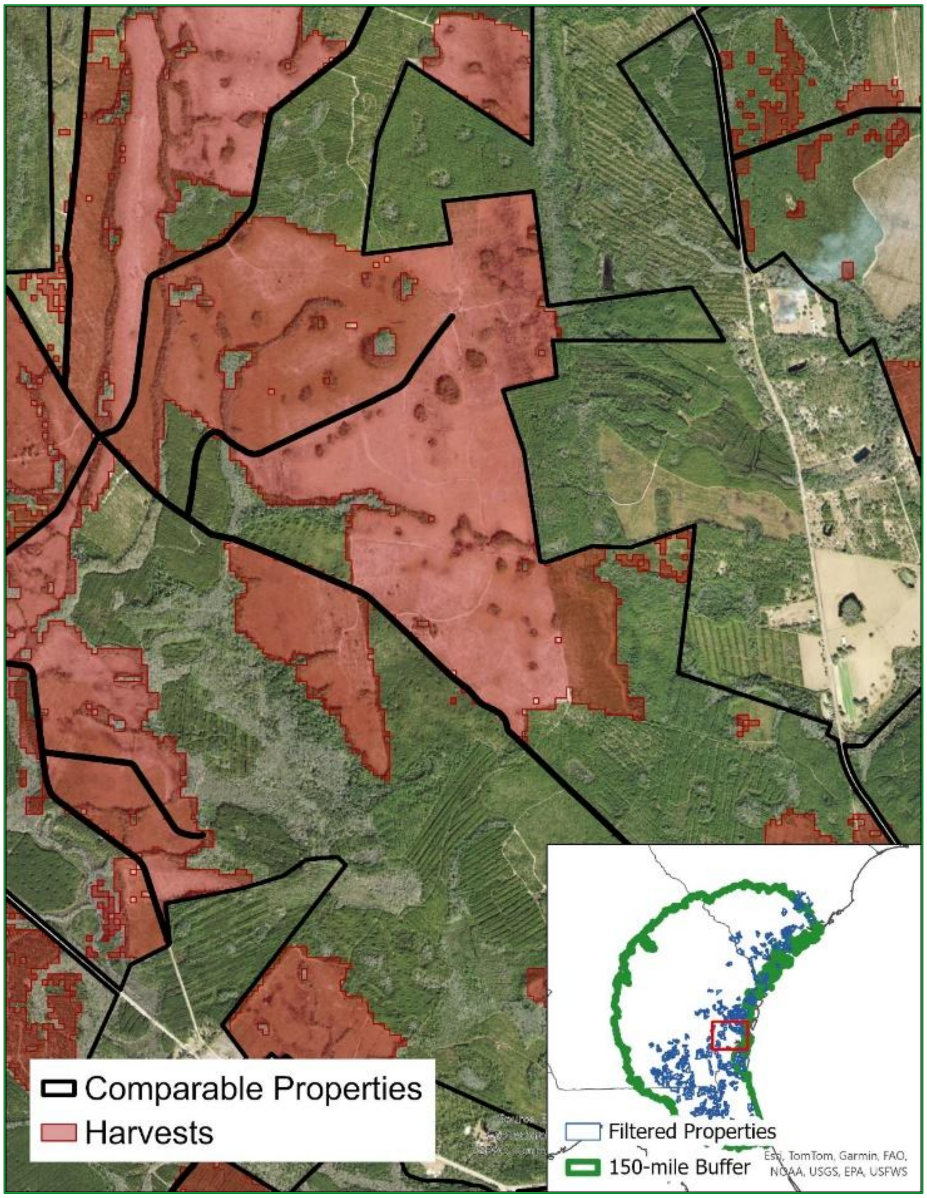


Step 5 Dissolve the Aggregated Harvests layer using the Aggregated Forest Loss layer's ID field.

Step 6 Calculate the acreage of all polygons in the Aggregated Harvests layer using the Calculate Geometry tool. Delete all polygons less than 1 acre in size.

Step 7 Dissolve all polygons in the Aggregated Harvests layer. The output layer will be referred to as the Harvests layer (Figure 13), and it is used in Section 7 if testing and approving a model other than GLAD and LCMS to identify harvested areas.

Figure 13: Harvests layer after removing areas of natural disturbance and areas smaller than the minimum mapping unit



4.1.6.4 Forest Cover Stratification

Forest cover stratification is necessary to determine the extent of forestland, which is required to determine whether the minimum harvest threshold (i.e., harvesting at least 0.2% of forestland per year) and the geographic size requirements (Section 4.1.7) have been met for eligibility. Forest cover stratification is also necessary to remove areas detected as harvests (i.e., in the Harvests layer) occurring on agricultural or other non-forested areas.

In this way, stratification is a safeguard that helps remove falsely detected timber harvests that should not inform the calculation of Harvest Intensity. Harvest Intensities must be substantiated for each forest cover type. This process is distinct from stratification for the purpose of carbon stock estimation, although the same stratification may be used for both purposes as applicable.

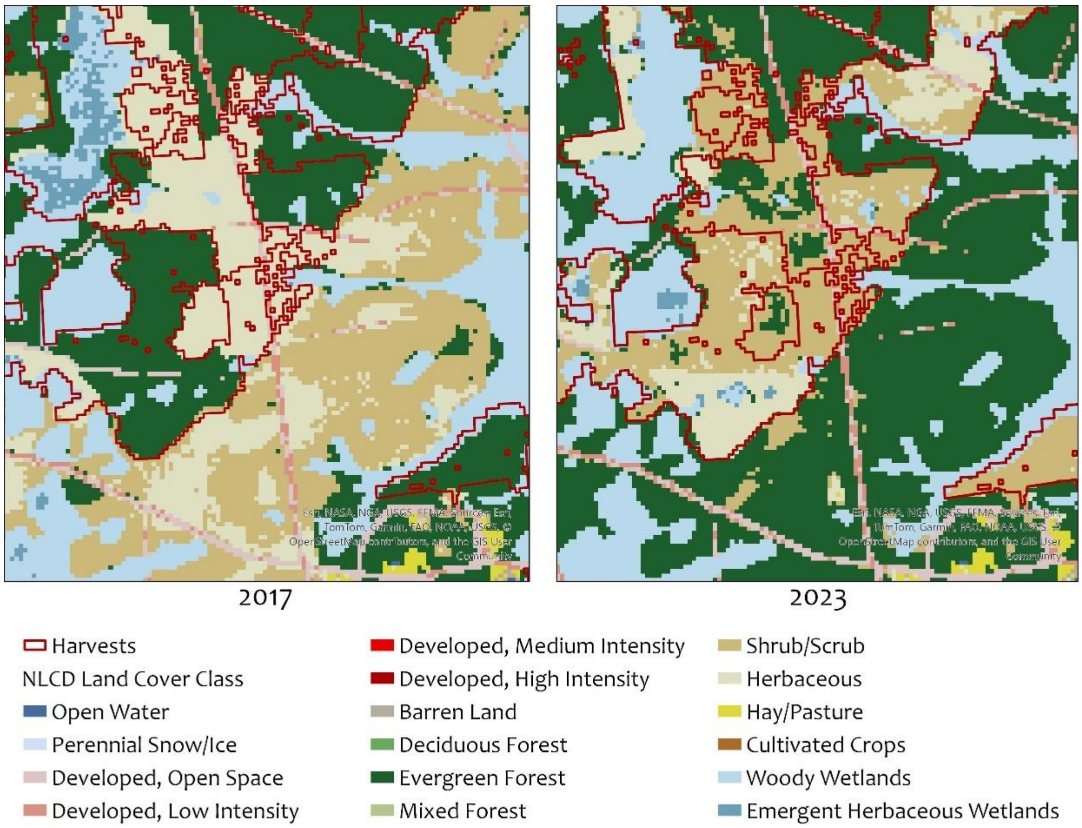
After creating the Harvests layer, the next step is to stratify the project property and eligible comparable properties, consistently applying the same methods and datasets. At minimum, forest cover strata must use the classifications of the National Land Cover Database (NLCD),[11] which include Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands, and others. More refined forest cover stratifications (e.g., by species or FIA forest type) must be accompanied by verifiable evidence supporting the improved accuracy of the proposed stratification system relative to NLCD.

This demonstration uses the annual NLCD product suite to identify the most recently published version of the NLCD that represents forest cover at the end of the lookback period. However, recently harvested areas may be assigned a non-forest stratum such as Barren Land, Shrub/Scrub, Herbaceous, or Hay/Pasture due to harvesting that occurred during the lookback period. To overcome this, recently harvested areas (i.e., the Harvests layer) should be stratified using the annual NLCD data from two years preceding the defined lookback period and reasonable efforts must be made to correct the classification of recently harvested lands.

In this example demonstration, the 2023 data is first applied to determine an initial forest cover stratification layer, and then the 2017 data is substituted for areas of identified harvests (Figure 14).

[11] The annual NLCD data is available here: https://www.usgs.gov/centers/eros/science/annual-national-land-cover-database

Figure 14: Comparison of National Land Cover Database stratification of recently harvested areas from 2017 and 2023



The acreage in each forest cover stratum is required to calculate Harvest Intensity of observed harvest treatments. The following steps are an approved method to stratify comparable properties and their harvested areas. The results of Steps 11 and 12 may be input into Table 1 of the Harvest Intensity Calculations worksheet:

Step 1 Download the most recent NLCD layer representing the beginning and end of the lookback period (hereafter referred to as the 2023 NLCD and 2017 NLCD layers, respectively).

Step 2 Clip both the 2023 NLCD layer and the 2017 NLCD layer to the 30-m Buffered Properties layer. This creates new layers containing NLCD data for only the eligible comparable properties.

Step 3 Project the clipped NLCD layers to the same coordinate system as the other layers.

Step 4 Obtain 2017 NLCD data for the pixels overlapping with the Harvests layer using the Extract by Mask tool.

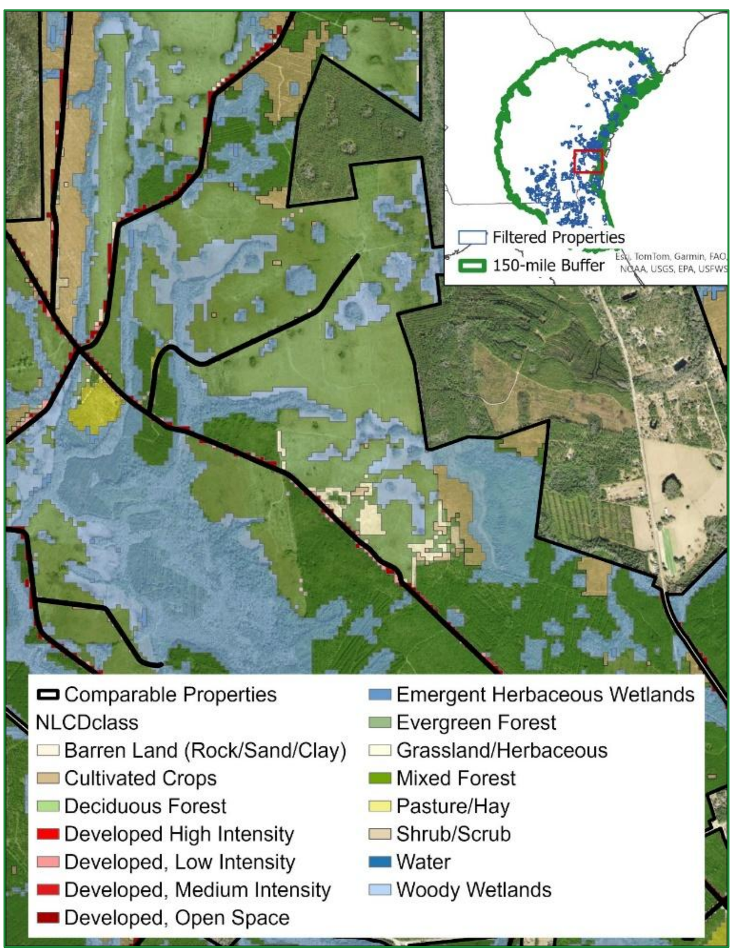
Step 5 Using the Extract by Attributes tool, extract the 2017 NLCD pixels (from Step 4) that belong to the classes of interest: Deciduous Forest, Evergreen Forest, Mixed Forest, and Woody Wetlands.

Step 6 Replace the 2023 NLCD pixels overlapping with the Harvests layer with the extracted pixels from the 2017 NLCD using the Mosaic to New Raster tool. Note that the order in which the layers are added is important. The first layer should be the extracted pixels from the 2017 NLCD and the second layer should be the 2023 NLCD layer. Ensure the Mosaic Operator is set to First.

Step 7 Convert the new NLCD raster into polygons using the Raster to Polygon tool, choosing to not simplify polygons.

Step 8 Intersect the NLCD polygons layer with the Similar Ownership Filtered Properties layer. The output layer should contain NLCD data for each property and will be referred to as the NLCD Properties layer (Figure 15).

Figure 15: NLCD data from 2017 and 2023 for comparable properties



Step 9 Dissolve the layer created in the previous step using the property ID and NLCD classes.

Step 10 Select the NLCD classes considered forestland using the Select by Attribute tool. The NLCD classes to be considered forestland are Deciduous Forest, Evergreen Forest, Mixed Forest, and Woody Wetlands. Select each class individually and create four new layers (using the Make Layer From Selected Features tool) for each forestland NLCD class.

Step 11 Calculate the acreage for each forestland NLCD class layer using the Calculate Geometry tool. Make sure to identifiably name the acreage fields for each different layer. For example, the Evergreen Forest layer's acreage field could be named "EvergreenAcreage" and the Deciduous Forest layer's acreage field could be named "DeciduousAcreage". This will be used as similarity criteria in Section 5.1 below.

Step 12 Merge the four forestland NLCD class layers. Dissolve the output layer by property ID. This layer will be referred to as the Forestland layer, and it will be used in Section 5 below.

Step 13 Join the calculated acreages for each of the four NLCD class layers to the Similar Ownership Filtered Properties layer using the Join Field tool and the property ID.

Step 14 Sum the acreages for each NLCD class inside each property using the Calculate Field tool to obtain the forestland acres per property. This will be used in Sections 4.1.7 and 5.1.3 below.

Step 15 Divide the summed acreages for each NLCD class per property by the total forestland acres per property using the Field Calculator tool. This calculates the percentage of forestland in each NLCD class per property. This will be used as similarity criteria in Section 5.1 below.

In regions with significant access constraints (e.g., interior Alaska), projects may define a geographically delineated access threshold (e.g., within 2 aerial miles of an existing transportation network), within which forestland is considered accessible and beyond which it is not. This access threshold may be overlaid on the NLCD-derived forestland layers to calculate the total *accessible* forestland acres per property, to be used in place of total forestland acres per property in all proceeding steps. Projects seeking to implement this option must obtain advance written approval from ACR.

The harvested acreage per stratum is required to calculate Harvest Intensity of the observed harvest treatments. The following steps are an approved method to identify the number of acres harvested in each stratum (Section 6, Step 1). The results of Step 5 (below) may be input into Table 2 of the Harvest Intensity Calculations worksheet:

Step 1 Intersect the NLCD Properties layer with the Harvests layer. The output layer should contain the harvested areas in each property for all NLCD classes.

Step 2 Dissolve the layer created in the previous step using the property ID and NLCD classes.

Step 3 Select the NLCD classes considered forestland (Deciduous Forest, Evergreen Forest, Mixed Forest, and Woody Wetlands) using the Select by Attribute tool. Select each class individually and create four new layers (using the Make Layer From Selected Features tool) with the acreages of their respective forestland NLCD class.

Step 4 Calculate the harvested acreage for each forestland NLCD class layer using the Calculate Geometry tool. Make sure to identifiably name the acreage fields for each different layer. For example, the Evergreen Forest layer's harvested acreage field could be named "EvergreenHarvAcreage" and the Deciduous Forest layer's harvested acreage field could be named "DeciduousHarvAcreage".

Step 5 Join the calculated harvested acreages for each of the four NLCD class layers to the Similar Ownership Filtered Properties layer using the Join Field tool and the property ID.

Step 6 Sum the harvested acreages for all forestland NLCD classes inside each property using the Calculate Field tool to calculate each property's forestland acreage harvested during the lookback period.

Step 7 Divide the harvested forestland acreage of each property by the forestland acreage on each property using the Calculate Field tool. This calculates each property's percentage forestland acreage harvested during the lookback period, which will be used in Section 5.3 below.

Once the percentage forestland harvested has been calculated, eligible comparable properties may be filtered to only those with harvest levels during the lookback period that are indicative of common practice forest management, using the steps below:

Step 1 Multiply the duration (years) of the defined lookback period by 0.2% to calculate the minimum percentage forestland harvested. Select all properties in the Similar Ownership Filtered Properties layer with less than the minimum using the Select by Attributes tool.

Step 2 Press delete to remove the properties.

4.1.7 GEOGRAPHIC SIZE

Eligible comparable properties must meet the geographic size specifications laid out in Section 4.1 (i.e., forestland acreage between 25% and 250% of the forestland acreage of the project property). Filtering by geographic size may be performed as follows:

Step 1 Select all properties from the Similar Ownership Filtered Properties layer with forestland acreage (created in Step 14 of Section 4.1.6.4) meeting the geographic size specifications using the Select by Attribute tool. In the demonstration, the forestland acreage of eligible comparable properties must be greater than 4,699.85 acres and less than 46,998.45 acres.

Step 2 Create a new layer using the Make Layer From Selected Features tool. Make sure to keep a unique ID for each property. The output layer will be referred to as the Eligible Comparable Properties layer.

The Eligible Comparable Properties layer is the basis for the property list included in the Eligible Comparable Properties worksheet found in the Comparable Properties Analysis Calculator. [12] The following sections for determining similarity contain steps performed within the GIS environment but also in this spreadsheet.

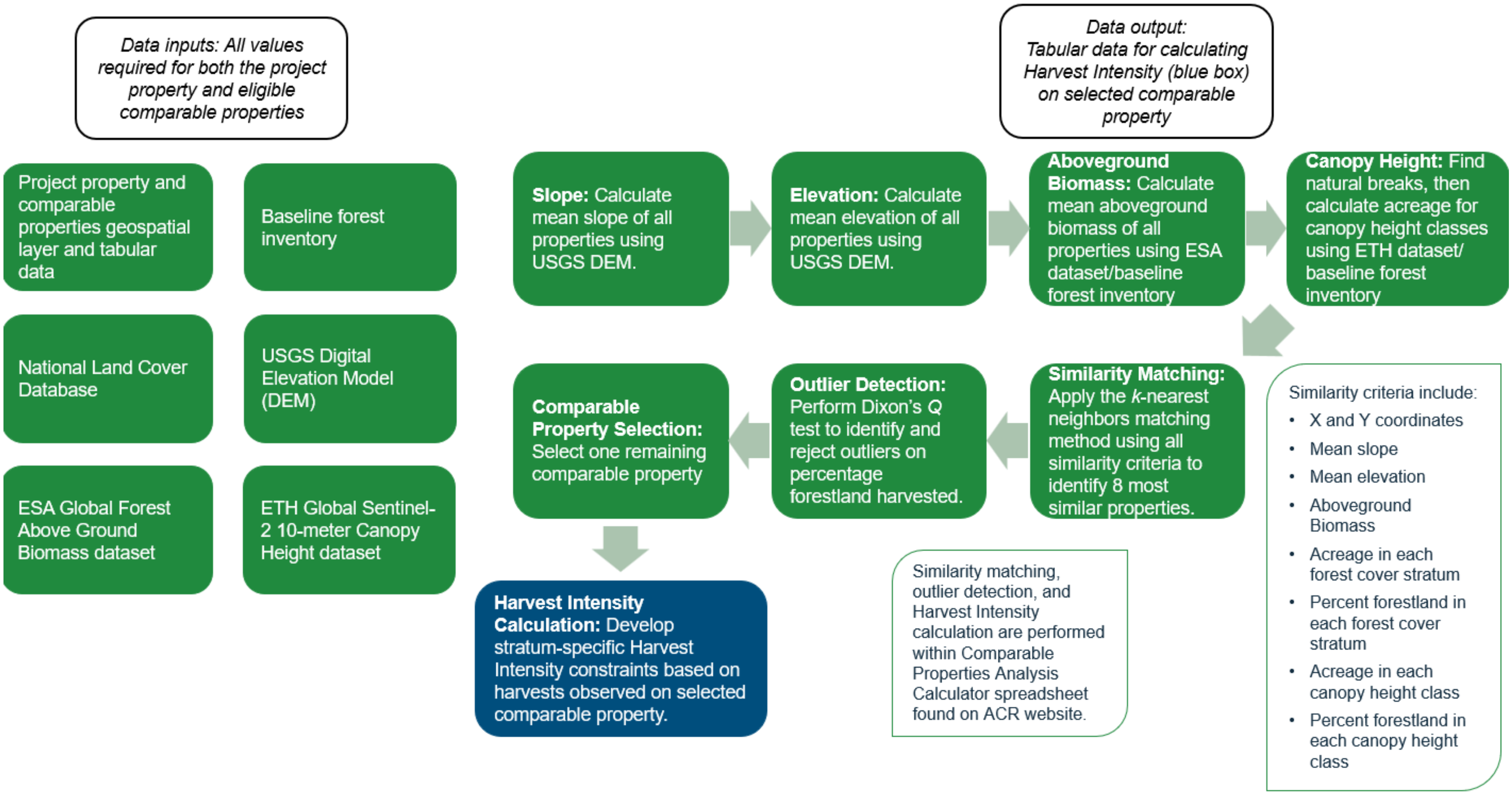
[12] Found on this tool's website.

5 Matching with Comparable Properties

Once eligible comparable properties have been determined and stratified, a matching process is implemented to determine the eight most similar comparable properties eligible for Harvest Intensity constraint development. The matching process identifies comparable properties with attributes most similar to conditions that would occur if the project property were managed according to the baseline scenario. As such, certain similarity criteria are determined using the baseline forest inventory.

Figure 16 summarizes the process for matching comparable properties and selecting one for calculating Harvest Intensity.

Figure 16: Matching with and selecting comparable properties for Harvest Intensity calculation



5.1 Similarity Criteria

The criteria for determining similarity are as follows:

Table 3: Similarity criteria and approved data sources

CRITERIA	APPROVED DATA SOURCE	UNITS; NOTES
X and Y coordinates (distance from the project property)	GIS	Geographic coordinates of the centroid of the property
Mean Slope	United States Geological Survey (USGS) Digital Elevation Model (DEM); Section 5.1.1	Degrees; ≤10-meter spatial resolution
Mean Elevation	USGS DEM; Section 5.1.1	Meters; ≤10-meter spatial resolution
Aboveground Biomass (AGB)	**Comparable Properties:** European Space Agency (ESA) Global Forest Above Ground Biomass; Section 5.1.2 **Project Properties:** Baseline forest inventory	Metric tons AGB per hectare **Comparable Properties:** ≤100-meter spatial resolution, use a version representing a point in time one year prior to the lookback period start date or more recent
Forestland acreage in each forest cover stratum (e.g., Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands)	NLCD; results of Step 11, Section 4.1.6.4	Acres
Percent forestland acreage in each forest cover stratum (e.g., Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands)	NLCD; results of Step 15, Section 4.1.6.4	Percent

Forestland acreage in each canopy height class	**Comparable Properties:** ETH Global Sentinel-2 10 meter Canopy Height; Section 5.1.3	**Project Properties:** Baseline forest inventory	Acres **Comparable Properties:** ≤10-meter spatial resolution, use a version representing a point in time one year prior to the lookback period start date or more recent
Percent forestland acreage in each canopy height class	**Comparable Properties:** ETH Global Sentinel-2 10 meter Canopy Height; Section 5.1.3	**Project Properties:** Baseline forest inventory	Percent **Comparable Properties:** ≤10-meter spatial resolution, use a version representing a point in time one year prior to the lookback period start date or more recent

Other data sources may be utilized, subject to verification and advance written approval by ACR. Once the data source(s) are approved, verification should focus on the process of applying the approved source rather than the results for any given property. The following sections provide details on the approved sources and how to utilize them to calculate the criteria used in similarity matching (Section 5.2).

5.1.1 SLOPE AND ELEVATION

Slope and elevation are included in the similarity ranking and matching process because topography informs the operability and accessibility of a given property for timber harvest and extraction. The following steps are an approved method to calculate the mean slope and mean elevation of eligible comparable properties and the project property for input into the matching process:

Step 1 Download the tiles of a USGS DEM with at least 10-meter resolution to overlap with the Eligible Comparable Properties layer. If downloading the 10-meter resolution layer, select the 1/3 arc-second DEM (Figure 17).

Step 2 Add the DEM layer to the map.

Step 3 Calculate the slope, selecting the DEM as the "Input surface raster", using the Surface Parameters tool. The 30-m Buffered Properties layer may be used as the "Input analysis mask" to improve performance.

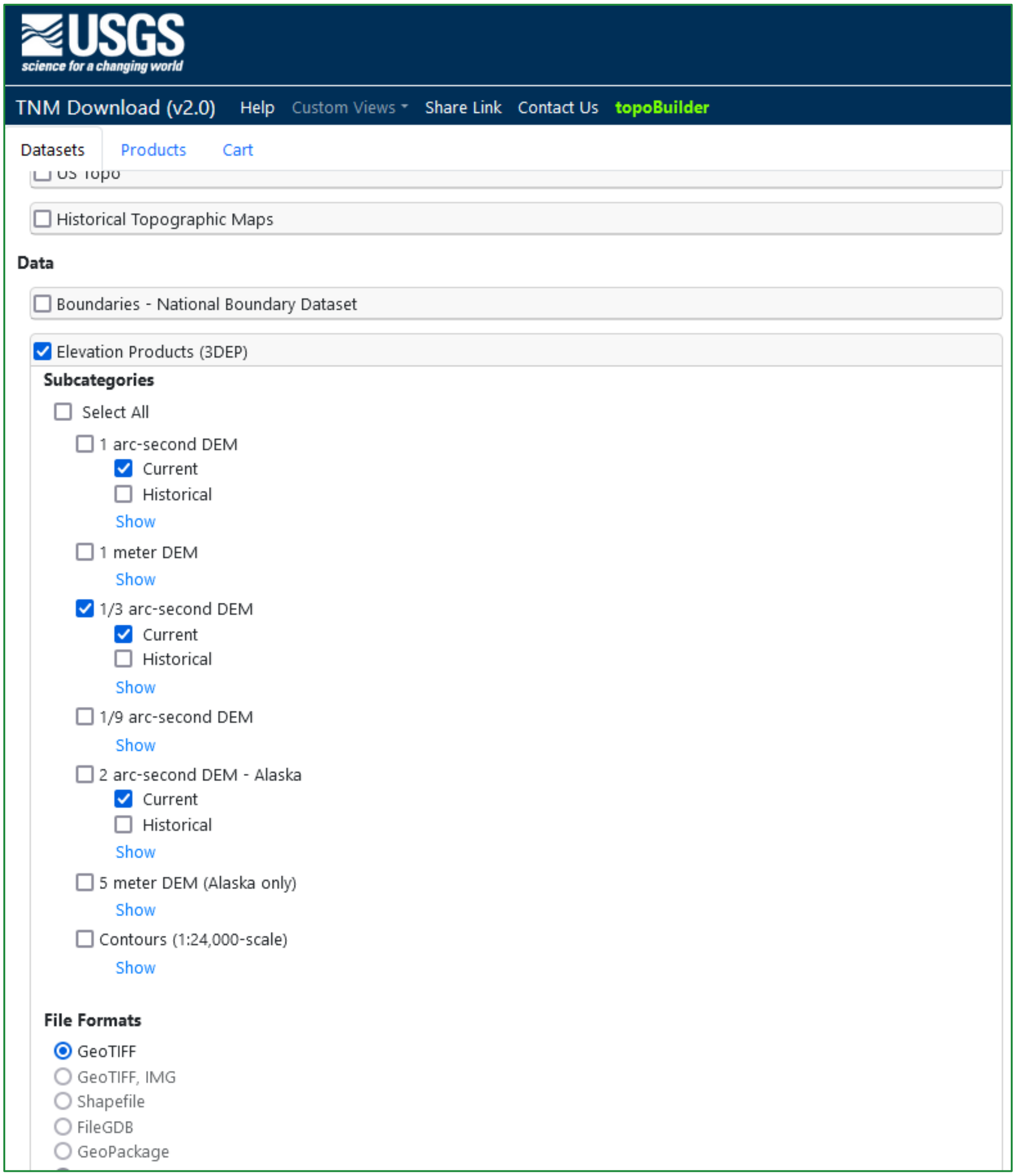
Step 4 Project the elevation and slope layers to the coordinate system used by the other layers.

Step 5 Calculate the mean elevation of each property's forestland, selecting the property ID as the "Zone Field", using the Zonal Statistics as Table tool with the Forestland layer created in Step 12 of Section 4.1.6.4.

Step 6 Join the mean elevation to the Eligible Comparable Properties layer using the Join Field tool and the property ID. The result will be the mean elevation in meters.

Step 7 Repeat Steps 5 and 6 with the slope layer. The result will be the mean slope in degrees.

Figure 17: Downloading the United States Geological Survey Digital Elevation Model



5.1.2 ABOVEGROUND BIOMASS

Aboveground Biomass (AGB) is included in the similarity ranking and matching process because it is an indicator of how much timber is available for harvest and thus affects the forest management of a property. The following steps are an approved method to calculate AGB of eligible comparable properties (Steps 1 through 3) and the project property (Steps 4 and 5) for input into the matching process:

Step 1 Download the ESA Global Forest Above Ground Biomass layer (from their website or from Google Earth Engine) that is most representative of the lookback period start date and project it to the same coordinate system as the other layers. The downloaded layer may be clipped to the 30-m Buffered Properties layer to improve performance. This is an example of a Google Earth Engine code that can be used to download the AGB data (and the canopy height data; Step 1 of Section 5.1.3). Add the 30-m Buffered Properties layer to the asset, import it into the code, and change its name to “area”.

Step 2 Add the AGB layer to the map. Calculate the mean AGB for each eligible comparable property using the Zonal Statistics as a Table tool and the Forestland layer created in Step 12 of Section 4.1.6.4.

Step 3 Join the mean column of the output table of the previous step with the Eligible Comparable Properties layer using the Join Field tool and the property ID.

Step 4 If determining Harvest Intensity for the initial validation (to be applied at the project Start Date), the project property’s mean AGB should be calculated according to Steps 1 through 3; skip Steps 4 and 5. If determining Harvest Intensity later in the project term (when observed AGB is not representative of the baseline model’s current conditions), calculate the mean AGB of the project property at the start of the relevant Reporting Period using the baseline forest inventory. This mean must be calculated and expressed to match the ESA Global Forest Above Ground Biomass layer: oven-dry weight of the stem, bark, branches and twigs (excluding stump and roots) of all living trees (excluding snags), expressed in tons per hectare.

Step 5 Edit the project property’s value of the previously joined column (Step 3) to equal its mean AGB as calculated using the baseline forest inventory (Step 4).

5.1.3 CANOPY HEIGHT

The distribution of a property’s canopy height is an important measure of forest structure that can be useful in determining its management (i.e., whether to harvest or not). While the merchantability of a property’s standing timber is difficult to directly assess with publicly available datasets, canopy height may be used as a readily available proxy. Thus, the similarity ranking and matching process considers each property’s distribution of canopy height.

The distribution of canopy height is categorized into three classes using the Jenks natural breaks optimization process,[13] which selects upper and lower bounds for each class to minimize variance based on the canopy height distribution of eligible comparable properties. These canopy height classes form the basis for comparing the project property's canopy height to that of comparable properties. Because baseline forest management is expected to affect canopy height distribution over time, the project property's canopy height distribution must be calculated using the baseline forest inventory, except at initial validation when remotely-sensed canopy heights are representative of the baseline model. Canopy height thresholds must be defined using the same unit (e.g., meters) as the approved canopy height dataset.

The Global Canopy Height 2020 dataset from ETH at 10-meter resolution is an approved source for determining canopy height. The higher resolution (1-meter) Global Canopy Height Map from Meta and the World Resources Institute may also be used, although its utilization is more computationally demanding. The following steps are an approved method to calculate the canopy height distribution of eligible comparable properties (Steps 1 through 12) and the project property (Steps 13-15) for input into the matching process:

Step 1 Determine the project property's canopy height distribution. If determining Harvest Intensity for the initial validation (to be applied at the project Start Date), the project property's canopy height distribution values and the Jenks natural breaks should be calculated using ArcGIS Pro according to Steps 3 through 5; skip to Step 3. If determining Harvest Intensity later in the project term (when observed canopy heights are not representative of the baseline model's current conditions), calculate the project property's canopy height distribution and the Jenks natural breaks using the baseline forest inventory with the R software environment or a similar software. Create a list that includes the maximum height of live trees[14] (excluding any snags) for each plot of the baseline forest inventory at the start of the relevant Reporting Period.

Step 2 Analyze the list of maximum live tree heights for Jenks natural breaks to establish 3 different height classes. This is an example of R code that can be edited and used to implement the getJenksBreaks()[15] function; the example R code also implements Steps 15 and 16 below. The output of this step is the lower bound of Class 1 and the upper bounds of the 3 canopy height classes. Class 1 is the shortest height class, Class 2 refers to the middle height class, and Class 3 refers to the tallest height class. If Class 1's lower bound does not equal 0 because it is not present in the baseline forest inventory, it

[13] See "Univariate classification schemes": De Smith, M. J., Goodchild, M. F., Longley, P. A. (2024). Geospatial Analysis: A Comprehensive Guide to Principles, Techniques and Software Tools. United Kingdom: Winchelsea Press. https://www.spatialanalysisonline.com/HTML/index.html?classification_and_clustering.htm

[14] Maximum height corresponds with GEDI's RH98, as used by the Global Canopy Height model: Lang, N., Jetz, W., Schindler, K., & Wegner, J. D. (2023). A high-resolution canopy height model of the Earth. *Nature Ecology & Evolution*, *7*(11), 1778-1789. https://doi.org/10.1038/s41559-023-02206-6

[15] https://search.r-project.org/CRAN/refmans/BAMMtools/html/getJenksBreaks.html

should be manually altered to include 0 values. Similarly, any pixels exceeding the upper bound of Class 3 are classified as Class 3 in Step 6 below.

Step 3 Download the Global Canopy Height 2020 dataset (from Google Earth Engine, or load it from the ArcGIS Living Atlas) and project it to the same coordinate system as the other layers. The downloaded layer may be clipped to the 30-m Buffered Properties layer to improve performance.

Step 4 If Jenks natural breaks were calculated using the baseline forest inventory according to Steps 1 and 2, skip to Step 6. Otherwise, select pixels within the canopy height layer that overlap with the Forestland layer (created in Step 12 of Section 4.1.6.4) filtered to the project property using the Extract by Mask tool.

Step 5 Open the Symbology options for this layer and select Classify as the Primary symbology. Use Natural Breaks (Jenks) as the method and use 3 classes. Find the lower bound of Class 1 and the upper bounds of the 3 canopy height classes. In this example (Figure 18), Class 1 is 0 to 7 meters, Class 2 is 7 to 17 meters, and Class 3 is 17 to 33 meters. If Class 1's lower bound does not equal 0 because it is not present in the project property's canopy height layer, it should be manually altered to equal 0. Similarly, any pixels exceeding the upper bound of Class 3 are classified as Class 3 in Step 6 below.

Figure 18: Finding canopy height classes using Jenks natural breaks

Step 6 Select pixels within the canopy height layer that overlap with the Forestland layer (created in Step 12 of Section 4.1.6.4) using the Extract by Mask tool (for all eligible comparable properties, not just the project property as done in Step 4). Classify the canopy height layer (clipped to the 30-m Buffered Properties layer) using the Reclassify tool, manually using the upper values of each class obtained in either Step 2 or 5. If any pixels from the canopy height layer clipped to the 30-m Buffered Properties layer exceed the upper bound of Class 3, make sure to include them in Class 3.

Step 7 Convert the classified canopy height raster into polygons using the Raster to Polygon tool, choosing to not simplify polygons.

Step 8 Intersect the Forestland layer with classified canopy height polygons.

Step 9 Dissolve the output layer by property ID and canopy height class.

Step 10 Calculate the acreage of each canopy height class inside each property using the Calculate Geometry tool on the dissolved output. This calculates each comparable property's forestland acreage in each canopy height class.

Step 11 Select all canopy height class 1 polygons from the dissolved output using the Select by Attributes tool.

Step 12 Join the calculated acreage to the Eligible Comparable Properties layer using the Join Field tool and the property ID.

Step 13 Repeat Steps 11 and 12 for canopy height classes 2 and 3, first selecting canopy height class 2 polygons (in Step 11) and then selecting canopy height class 3 polygons (in Step 11).

Step 14 Divide the acreages of each canopy height class by each property's total forestland acreage using the Field Calculator tool. This calculates each comparable property's percent forestland in each canopy height class.

Step 15 If determining Harvest Intensity for the initial validation, the project property's canopy height distribution values should be calculated according to Steps 6 through 14; skip to Step 18. If determining Harvest Intensity later in the project term, calculate the percentage of the project property's baseline forest inventory in each canopy height class. The number of plots assigned to each canopy height class is divided by the total number of plots to determine the project property's percent forestland in each canopy height class.

Step 16 Calculate the project property's forestland acreage in each canopy height class by multiplying the project property's total forestland acreage (Step 14 of Section 4.1.6.4) by the percentages in each canopy height class (Step 15).

Step 17 Edit the project property's values in the previously joined acreage in each canopy height class columns (Step 12) and the percent forestland in each canopy height class columns (Step 14) to equal the respective values calculated using the baseline forest inventory in Steps 15 and 16.

Step 18 Export the Eligible Comparable Properties layer's tabular data using the Export Table tool. This allows calculations for the following sections to be performed in a spreadsheet program.

5.2 Similarity Matching

Using the criteria defined above (Section 5.1), eligible comparable properties are evaluated for similarity to the project property using a *k*-nearest neighbors matching method, resulting in a similarity index for each property ($\mathrm{Sim_i}$). The similarity index is then used to rank properties by their similarity to the project property. The eight most similar comparable properties are considered matched. The calculations in this section are contained within the Eligible Comparable Properties worksheet of the Comparable Properties Analysis Calculator.[16]

The normalized Euclidian distance must be utilized to measure the relative similarity of each comparable property to the project property for all criteria. The following steps are required to determine the eight most similar comparable properties:

Step 1 Normalize the values of each criterion.

For geographic coordinates, mean slope, mean elevation, and aboveground biomass, use the following formula:

Equation 1: Criteria Value Normalization

$$Z_{i,j \in J_1} = \frac{x_{i,j} - \overline{x_j}}{\sigma_j}$$

WHERE

$Z_{i,j \in J_1}$	Z-score normalized value for criterion j for property i. Note that the project property $\in i$.
J_1	X coordinate of the centroid, Y coordinate of the centroid, mean slope, mean elevation, aboveground biomass.
$x_{i,j}$	Value for criterion j for property i.
$\overline{x_j}$	Mean of criterion j values for all properties, including the project property.
σ_j	Standard deviation of criterion j values for all properties, including the project property.

[16] Found on this tool's website.

For the acreage and percent values for each forest cover stratum and canopy height class, use the following formula to normalize the values and multiply them by the project property's percentage:

Equation 2: Weighted Criteria Value Normalization

$$Z_{i,j\in J_2} = \frac{P_{i=project,j}\left(x_{i,j} - \bar{x}_J\right)}{\sigma_j}$$

WHERE

$Z_{i,j\in J_2}$	Z-score normalized value for criterion **j** for property **i**, weighted by the project property's percent forestland in each forest cover stratum and canopy height class. Note that the project property ∈ **i**.
J_2	Forestland acreage and percent forestland in each forest cover stratum and canopy height class.
$P_{i=project,j}$	Project property's percent forestland in each forest cover stratum or canopy height class.
$x_{i,j}$	Value for criterion **j** for property **i**.
$\bar{x}_J$	Mean of criterion **j** values for all properties, including the project property.
σ_j	Standard deviation of criterion **j** values for all properties, including the project property.

Step 2 After all criteria values have been normalized, calculate the squared distance between the project property and each comparable property for each criterion.

Equation 3: Squared Difference

$$d^2_{i,j\in J} = \left(Z_{i=project,j} - Z_{i,j}\right)^2$$

WHERE

$d^2_{i,j\in J}$	Squared difference of the normalized values for criterion **j** between the project property and property **i**.

J	$J_1 \cup J_2$ (i.e., all criteria).
$Z_{i=project,j}$	Normalized value for criterion **j** for the project property (Equation 4 or 5).
$Z_{i,j}$	Normalized value for criterion **j** for property **i** (Equation 4 or 5).

Step 3 After the squared difference has been calculated for all criteria, calculate the Euclidean distance. Since the forest cover stratum and canopy height class values have been reduced in scale in proportion to the project property's forestland percentage (Equation 2), multiply each sum of squared differences by the number of forest cover strata or canopy height classes, respectively.

Equation 4: Normalized Similarity

$$\mathbf{Sim_i} = \sqrt{\sum\nolimits_{i,j\in J_1} d^2_{i,j\in J_1} + n\sum\nolimits_{i,j\in J_3} d^2_{i,j\in J_3} + 3\sum\nolimits_{i,j\in J_4} d^2_{i,j\in J_4}}$$

WHERE

Sim_i	Similarity index relative to the project property for property **i**.
J_1	X coordinate of the centroid, Y coordinate of the centroid, mean slope, mean elevation, aboveground biomass.
$d^2_{i,j}$	Squared difference of the normalized values for criterion **j** between the project property and property **i** (Equation 6).
n	The number of forest cover strata.
J_3	Forestland acreage and percent forestland in each forest cover stratum.
J_4	Forestland acreage and percent forestland in each canopy height class.

Step 4 Rank the eligible comparable properties by their similarity index (Sim_i; result of Equation 7). A lower similarity index indicates a better match and more similarity with the project property. Excluding the project property itself, select the eight properties with the lowest similarity index. These are the matched comparable properties.

5.3 Outlier Detection

Once the eight most similar (i.e., matched) comparable properties have been identified (Section 5.2), they are evaluated using a Dixon's Q test to identify and reject outliers on the percentage forestland acreage harvested during the lookback period (final Step 7, Section 4.1.6.4). The calculations in this section are contained within the Outlier Detection worksheet of the Comparable Properties Analysis Calculator.[17]

Prior to outlier detection, adjustments and safeguards for salvage harvests must be applied (Section 4.1.6.2). Matched properties with visually identified but undetected salvage harvests may have adjustments applied to their harvested acreages per forest cover stratum for the relevant year. If any matched property is subject to salvage harvests, the harvested acreages per forest cover stratum per year must be limited to not exceed 10%. The updated harvested acreages per forest cover stratum must replace those calculated in the final Step 4 of Section 4.1.6.4, resulting in updated percentage forestland acreages for the affected properties to be used in outlier detection.

If the property with the highest percentage forestland acreage harvested is rejected as an outlier, it shall be replaced with the next most similar property. The Dixon's Q test shall be repeated on the new set of eight comparable properties until the property with the highest percentage forestland acreage harvested is accepted and no outliers are detected. This process ensures that the final list of matched comparable properties does not contain a property harvesting in excess of common practice, relative to the other matched properties. Repeating the test without changing the significance level increases the likelihood of detecting an outlier where there is none (Type 1 error), but this is acceptable given the resulting conservatism. This test is performed one-tailed with a significance level of 10%.

At the Project Proponent's discretion the project property itself may be considered matched and, subject to outlier detection, potentially available for selection. If opting to do so, nine properties will be included in the Dixon's Q test.

The following steps are required to identify and reject outliers from the matched properties:

Step 1 Copy and paste the attributes for the eight (or nine) matched comparable properties, including the percentage forestland acreage harvested during the lookback period (hereafter referred to as percentage harvested), to the Outlier Detection worksheet found in the Comparable Properties Analysis Calculator.[18]

Step 2 Sort the copied properties by their percentage harvested from lowest to highest.

[17] Found on this tool's website.

[18] Found on this tool's website.

Step 3 Calculate the Q value for the highest percentage harvested value using the Outlier Detection worksheet and the following formula:

Equation 5: Dixon's *Q* test

$$Q_n = \frac{\%FH_n - \%FH_{n-1}}{\%FH_n - \%FH_1}$$

WHERE

Q_n	Q value for the property with the highest percentage harvested value.
$\%FH_n$	Highest percentage harvested value.
$\%FH_{n-1}$	Second highest percentage harvested value.
$\%FH_1$	Lowest percentage harvested value.

Step 4 Compare the calculated Q value (Q_n; Equation 8) with the Q critical value. The Q critical value at the 10% significance level for eight properties ($n=8$) is 0.3979, and the Q critical value at the 10% significance level for nine properties ($n=9$) is 0.3704.[19] If the calculated Q value is greater than the Q critical value ($Q_n > 0.3979$ for $n=8$, or $Q_n > 0.3704$ for $n=9$), the highest percentage harvested is considered an outlier. This property must be rejected from the list of matched comparable properties available for selection. Otherwise, all values are accepted and no matched properties are rejected; skip Step 5.

Step 5 If an outlier was detected and a property rejected, replace the rejected property with the next most similar comparable property and repeat Steps 1 through 4 on the new set of comparable properties.

5.4 Comparable Property Selection

Once any outliers have been identified and removed from the list of matched comparable properties, select one of the remaining matched properties to be used to calculate Harvest Intensity.

[19] Verma, S. P., & Quiroz-Ruiz, A. (2006). Critical values for six Dixon tests for outliers in normal samples up to sizes 100, and applications in science and engineering. *Revista mexicana de ciencias geológicas*, *23*(2), 133-161. https://www.scielo.org.mx/scielo.php?script=sci_arttext&pid=S1026-87742006000200003

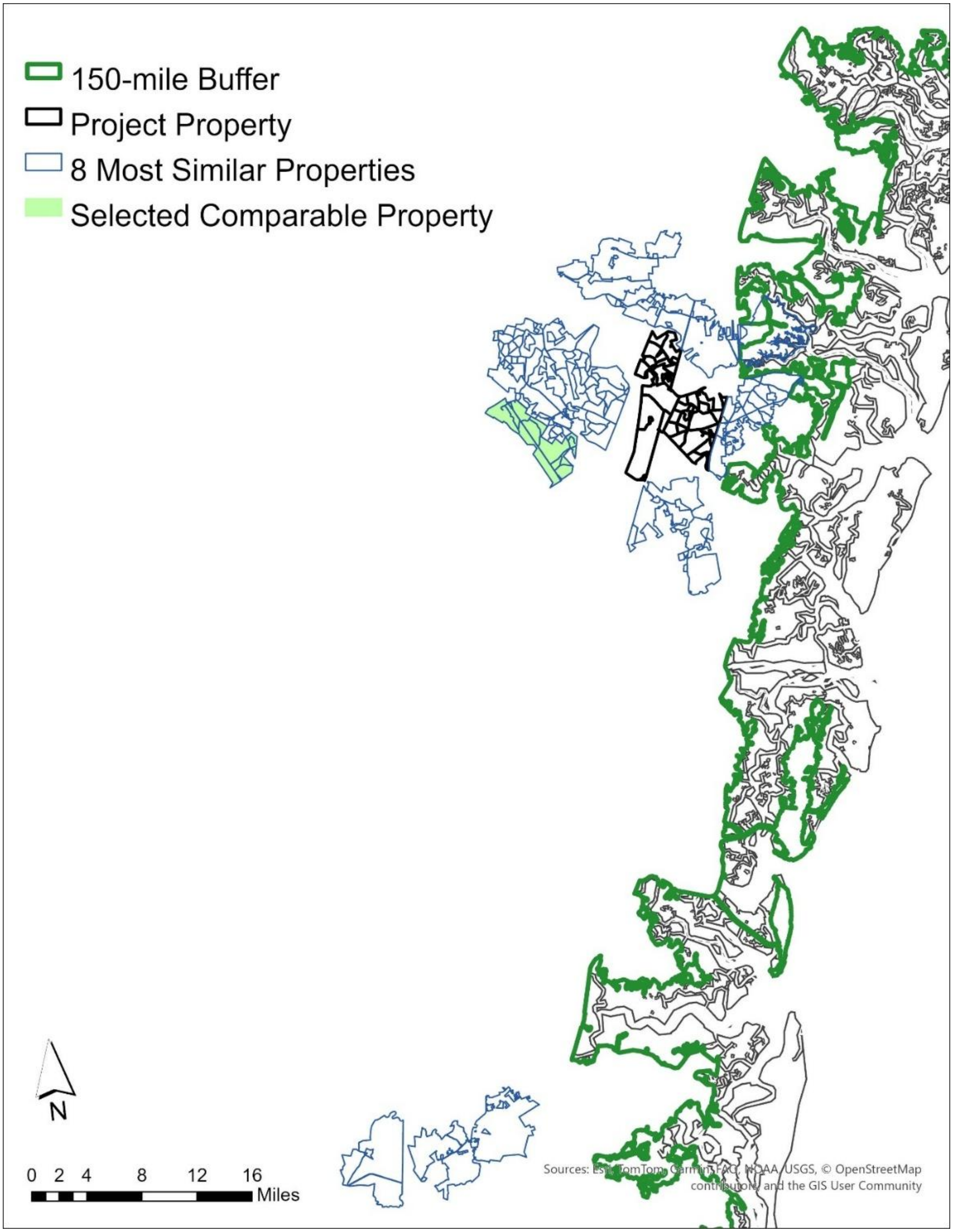
In this demonstration's example, the highest percentage harvested value was not considered an outlier, so all matched properties are available for selection and the property with the highest percentage harvested value was selected to calculate harvest intensity (Table 4 and Figure 19).

Table 4: Similarity criteria and other attributes of example project property and selected comparable property

CRITERIA AND ATTRIBUTES	EXAMPLE PROJECT PROPERTY	SELECTED COMPARABLE PROPERTY
Percentage Forestland Acreage Harvested during the Lookback Period	38%	53%
Similarity Index (Sim_i)	0.00	2.76
Ownership Description	Private Industrial Timber Company	Private Industrial Timber Company
Forestland Acreage	18,945 acres	8,067 acres
Distance from Project Property	0 miles	3 miles
Mean Slope	0.7°	0.6°
Mean Elevation	4.7 meters	7.4 meters
Aboveground Biomass (AGB)	95.5 metric tons/hectare	97.5 metric tons/hectare
Forestland acreage in each forest cover stratum: Deciduous Forest; Evergreen Forest; Mixed Forest; Woody Wetlands	15; 12,496; 0; 6,288	4; 5,346; 0; 2,718
Percent forestland in each forest cover stratum: Deciduous Forest; Evergreen Forest; Mixed Forest; Woody Wetlands	0%; 66%; 0% 33%	0%; 66%; 0%; 34%

Forestland acreage in each canopy height class: Class 1; Class 2; Class 3	1,958; 4,166; 12,675	1,032; 1,829; 5,207
Percent forestland in each canopy height class: Class 1; Class 2; Class 3	10%; 22%; 67%	13%; 23%; 65%

Figure 19: Matched comparable properties and the selected comparable property



6 Calculating Harvest Intensity

Once a comparable property is selected, GHG projects must determine the Harvest Intensity of the comparable property's observed harvest treatments.

The following general steps are followed when calculating the Harvest Intensity of a harvest treatment within a given forest cover stratum.

Step 1 **Identify the number of acres harvested in each stratum.** The number of acres harvested must consider all harvest treatments of similar percent biomass removed per acre.

Step 2 **Identify the average percent biomass removed per acre.** The percent biomass removed is relative to the sum of the above and belowground live biomass carbon and above and belowground standing dead wood (if included) pools. Harvest treatments may be separated by distinct treatment type or may be grouped together and averaged for each forest cover stratum. Averaging must only consider the relevant time period.

Step 3 **Divide the number of acres harvested by the total stratum acres to calculate the percent stratum area harvested.** The stratum acres must consider the forest cover stratification determined according to Section 4.1.6.4.

Step 4 **Divide the percent stratum area harvested by the number of years to calculate an annual harvest rate for each stratum.**

Step 5 **Multiply the percent biomass removed per acre by the percent stratum area harvested per year to calculate Harvest Intensity.** Harvest Intensity is expressed as a percentage.

The Harvest Intensity Calculations worksheet (found in the Comparable Properties Analysis Calculator[20]) and tables found therein are referenced in the sections below and must be utilized.

6.1 Comparable Property Harvest Intensity

The steps in Section 6 are applied to the selected comparable property (Section 5.4), which results in a determination of Harvest Intensities that are then used in constraint development (Section 6.2). Tables 1 and 2 of the Harvest Intensity Calculations worksheet must be completed following the

[20] Found on this tool's website.

Directions found therein to calculate the comparable property Harvest Intensity per forest cover stratum. If using the approved methods demonstrated by this tool (i.e., using GLAD and LCMS), the average percent biomass removed per acre may be assumed to be 100% (Table 2; row 10), given the technical limitations of detecting areas of partial harvests (i.e., thinning).[21] [22] If using a custom forest loss model the percent biomass removed per acre must be determined according to Section 7.4.

For the purpose of calculating comparable property Harvest Intensity, management records may be used in addition to (or in place of) harvest information derived from remote sensing. Management records (e.g., past timber sale data) may be used if the harvested spatial extent and percent biomass removed per acre can be verifiably determined. Management records may come from a participating entity (e.g., Project Proponent, landowner) or another landowner/forest manager and must be substantiated with verifiable evidence (e.g., published data of harvests on public lands, Professional Forester attestation, mill reports, scaling tickets).

6.2 Constraint Development

To develop constraints for parameterizing the baseline model based on the Harvest Intensities of the selected comparable property, projects must first identify the baseline's average percent biomass removed per acre for the Crediting Period (Table 4 of the Harvest Intensity Calculations worksheet) using modeled outputs from the baseline scenario. Within each forest cover stratum, percent biomass removed per acre may be averaged for similar harvest treatments. Projects then develop constraints by applying the inverse operations of the general steps for Harvest Intensity calculation (Section 6; Table 4 of the Harvest Intensity Calculations worksheet).

Constraining baseline harvests in a single year to the selected comparable property's Harvest Intensity may inappropriately limit inter-year harvest variation. This may be exacerbated on smaller project properties, which may be subject to periodic harvests of higher relative intensity. To account for the effect of averaging time in the Harvest Intensity calculation, projects must calculate a scaling factor to be used in determining the annual constraint (Equation 9). The Annual Harvest Intensity Factor may range from 1.25 to 3, depending on the total project property acreage.

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[21] Stehman, S. V., Pengra, B. W., Horton, J. A., & Wellington, D. F. (2021). Validation of the US geological survey's land change monitoring, assessment and projection (LCMAP) collection 1.0 annual land cover products 1985–2017. *Remote sensing of environment*, *265*, 112646. https://doi.org/10.1016/j.rse.2021.112646

[22] Despite recent improvements to selective logging detection, the GLAD dataset (lossyear) is still described as "[f]orest loss during the period 2000-2022, defined as a stand-replacement disturbance, or a change from a forest to non-forest state." https://data.globalforestwatch.org/documents/941f17325a494ed78c4817f9bb20f33a/explore

Equation 6: Annual Harvest Intensity Factor

$$\textbf{if } \left[\text{Area}_{\text{project}} < 5,000\right] \textbf{ then } \text{HI}_{\text{F}} = \left(\left[\frac{(5,000 - \text{Area}_{\text{project}})}{5,000}\right] \times 1.75\right) + 1.25$$

or

$$\textbf{if } \left[\text{Area}_{\text{project}} \geq 5,000\right] \textbf{ then } \text{HI}_{\text{F}} = 1.25$$

WHERE

HI_F	Annual Harvest Intensity Factor (unitless).
$Area_{project}$	Total project property area (acres).

This factor is multiplied by the acres harvested per year (based on comparable property Harvest Intensity and the baseline percent biomass removed per acre) to calculate the annual constraint (Table 4 of the Harvest Intensity Calculations worksheet). The cumulative constraint is calculated by multiplying the acres harvested per year by the number of years in the Crediting Period (20).

6.3 Harvest Intensities Check

Once a baseline harvest schedule has been developed, final checks must be performed to ensure proper implementation and standardize validation/verification. For *ex-ante* projections at initial validation, checks ensure that Harvest Intensities of the selected comparable property were not exceeded, both in each single year (Table 5 of the Harvest Intensity Calculations worksheet) and cumulatively during the Crediting Period (Table 6 of the Harvest Intensity Calculations worksheet).

Baseline harvest treatments included in these checks are inclusive of any regeneration or partial harvests. Intermediate treatments (e.g., pre-commercial thinning) and other non-commercial harvest treatments should not be included when calculating baseline Harvest Intensity.

These checks are also performed as part of the dynamic evaluation (according to the *ACR IFM Methodologies Tool for Dynamic Evaluation of Baselines*). Harvest Intensities for the Reporting Period are checked during the Observed Conditions Assessment (Table 7 of the Harvest Intensity Calculations worksheet). Harvest Intensities for the remainder of the Crediting Period are checked during the Periodic Modeling Assessment (Table 8 of the Harvest Intensity Calculations worksheet).

To prepare for these checks, projects must first identify the baseline's average percent biomass removed per acre for the relevant time period (e.g., the Crediting Period, a single year, or the

Reporting Period) using modeled outputs from the baseline scenario, averaging similar harvest treatments within each forest cover stratum. After averaging similar harvest treatments, there may still be multiple dissimilar (i.e., unaveraged) harvest treatments per forest cover stratum; these Harvest Intensities must be combined, which calculates the total Harvest Intensity per forest cover stratum.

When checking annual or Reporting Period Harvest Intensities, comparable property Harvest Intensity must be multiplied by the Annual Harvest Intensity Factor (Equation 9; Tables 5 and 7).

When checking cumulative Harvest Intensities, percent stratum area harvested must be divided by the number of years remaining in the Crediting Period (20 years at validation, or less during a Periodic Modeling Assessment; Tables 6 and 8) to calculate an annual harvest rate prior to calculating Harvest Intensity.

If the selected comparable property's Harvest Intensity (Table 2 of the Harvest Intensity Calculations worksheet) exceeds the total Harvest Intensity per forest cover stratum, then the baseline Harvest Intensities applied to that forest cover stratum are substantiated. For any forest cover stratum that cannot be substantiated, the baseline Harvest Intensities must be reduced such that they are equal to or less than the comparable property Harvest Intensities per forest cover stratum.

Lastly, the application of the Annual Harvest Intensity Factor (Equation 9) must be checked over the crediting period. Since a project property will undergo multiple comparable property analyses resulting in multiple sets of Harvest Intensities throughout the Crediting Period, a check is required to ensure that the Annual Harvest Intensity Factor is not overutilized in constraint development (Table 9 of the Harvest Intensity Calculations worksheet). At each Periodic Modeling Assessment, a proposed five-year application of the Annual Harvest Intensity Factor must be submitted for verification, expressed as a fraction of the baseline's Reporting Period Harvest Intensities relative to the comparable property Harvest Intensities. This fraction can range from 0 (if no baseline harvest took place) to 3 (i.e., the maximum value of the Annual Harvest Intensity Factor). These fractions are annualized over the forthcoming five years, until the next Periodic Modeling Assessment or the end of the Crediting Period, and the annualized fractions are recorded in Table 9. The fractions are averaged throughout the 20-year Crediting Period, and by the end of the Crediting Period, this average may not exceed 1.0. If fractions from earlier Periodic Modeling Assessments exceed 1.0, successive Periodic Modeling Assessments must ensure that future Reporting Period fractions result in a 20-year average of 1.0 or less, which indicates that baseline Harvest Intensities did not exceed observed Harvest Intensities on average over the Crediting Period.

7 Approval Process for Custom Forest Loss Identification Models

This section describes the requirements for testing and approving custom models (i.e., not GLAD or LCMS) that identify harvested areas using remote sensing technology (i.e., custom change detection models). The approved default datasets and methods utilized by this tool's example demonstration (i.e., GLAD and LCMS) do not require testing per this section.

Projects may utilize custom models developed by project participants or models developed by non-project participants (e.g., government agencies, universities, academic or research cooperatives, or private companies). In either case, the custom models must be used to create a layer of harvest polygons. This layer may integrate the default datasets and methods for identifying forest loss (i.e., GLAD and LCMS; the Harvests layer created in Step 7 of Section 4.1.6.3), producing a harvest layer that incorporates all harvest polygons from GLAD and LCMS with additional areas detected solely by the custom model. Even if incorporating harvest polygons from the default datasets and methods, the custom model's harvest layer as a whole (including areas identified by GLAD, LCMS, and the custom model) is subject to testing for approval.

Custom models must make predictions at a spatial resolution (i.e., pixel size) of 30 meters or finer and a temporal resolution (i.e., frequency of data collection/processing) of 1 year or less.[23] Post-processing or modeling approaches may only be applied to the output of the custom model (prior to incorporation into a harvest layer) for two purposes: to remove areas of natural disturbance, and to apply a minimum mapping unit; all other post-processing or manipulation of the custom model's output is not allowable.

Prior to approval by ACR, custom models are subject to testing to confirm they have a higher F1 score than the combined GLAD and LCMS datasets (i.e., the Harvests layer; Section 4.1.6.3) in the relevant geography (Section 7.2). Custom models may be approved at two different scales:

Option 1 **Model approval for an individual GHG project.** Models may be used to identify harvests for an individual GHG project.

[23] Gao, Y., Skutsch, M., Paneque-Gálvez, J., & Ghilardi, A. (2020). Remote sensing of forest degradation: a review. *Environmental Research Letters*, *15*(10), 103001. https://doi.org/10.1088/1748-9326/abaad7

Option 2 **Model approval for a region based on a random sampling approach.** Models may be used by multiple GHG projects based upon a single successful regional approval process. The region for which the model is approved for use must be explicitly defined. This region becomes a sampling frame, within which samples are selected for classifying ground truth data. Any GHG project whose 150-mile (or expanded as applicable; Section 4.1.1) buffer is located entirely within the approved model's region may use the approved model. While there are no size limits to this region, ground truth data sample size increases linearly with region size.

The scale chosen for model approval has implications for the quantity of ground truth data that is required.

As part of its assessment, ACR may direct questions to the model developer, and a model may need to be revised prior to approval. Submission of a custom model is not a guarantee of ACR approval. Approval of a custom model will be provided in writing and is specific to the version of the model approved. Model updates require re-review and approval. Approval of a model does not guarantee a positive validation or verification.

7.1 Ground Truth Data

To test the forest loss model for accuracy, its output must be compared to independent ground truth data sources that identify harvests. To maintain independence, ground truth data used for validation per this section may not be used as training data for model development. This classification of the ground truth data forms the basis for assessing model performance.

Ground truth data may come from two sources:

- Spatially explicit historical harvest data from project participants, public records, public agencies, or other landowners, according the following specifications:
  - At minimum, the boundaries of harvested areas and coordinates of the polygons must be included.
  - Harvest data must be timestamped and within the defined lookback period (Section 2).
  - Harvest data must be spatially and temporally complete (i.e., all harvests and non-harvests within its specified area and time period must be included) to the best of the knowledge of the project participants.
  - Harvest polygons must be at least 1 acre in size each.
  - If non-harvest polygons are not explicitly provided, a systematic and unbiased approach to their creation must be implemented. Non-harvest polygons must be at least 1 acre in size.

- High-resolution imagery subject to visual interpretation and digitized to produce harvest and non-harvest polygon layers, according to the following specifications:
  - The process for collecting imagery must strive to capture the heterogeneity of the landscape in the sampling frame (either a project's filtered comparable properties or the defined region) through a stratified random sampling approach, using cluster sampling and stratification by forest cover strata and harvest occurrence within each cluster to increase efficiency.[24] [25]
    - For Option 1 (model approval for a individual GHG project), the sampling frame is defined by the project properties' comparable properties filtered by all eligibility criteria except harvest occurrence and geographic size. Alternatively, the project may define the sampling frame following the optional process described Section 7.5, which efficiently limits where the custom model must be applied. The target population shall be defined as forestland located within the comparable properties of interest.
    - For Option 2 (regional model approval), the explicitly defined region becomes a sampling frame, and the target population shall be defined as forestland of an ownership class that is eligible to enroll a GHG project using the applicable methodology (e.g., non-federally owned forestland in the USA). Forestland should be defined according to this Tool (the Forestland layer created in Step 12 of Section 4.1.6.4) .
    - Regardless of the Option chosen, a grid of equally sized 10-acre (± 1 acre) square clusters must be randomly allocated across the sampling frame. Clusters which do not include any of the target population (e.g., forestland located within the comparable properties of interest, or non-federally owned forestland) must be discarded. The remaining clusters must be assigned numbers in sequential order in a geographically systematic fashion (e.g., starting from the north and proceeding eastward).
    - From the start of the sequence, clusters which include less than 50% of the target population (e.g., forestland located within the comparable properties of interest, or non-federally owned forestland) must be aggregated with the neighboring cluster with the fewest pixels of the target population, selecting clusters for aggregation in a geographically systematic fashion (e.g., starting from the north and proceeding eastward) in cases of multiple neighboring clusters equally having the fewest pixels of the target population. This step is repeated until each cluster contains at least 50% of the target population. This produces a map of clusters where some have been aggregated and others have not.
    - The resulting clusters shall be assigned to a stratum based on two factors: which forest cover stratum represents the majority of the area within the cluster, and whether harvests are

[24] Olofsson, P., Foody, G. M., Stehman, S. V., & Woodcock, C. E. (2013). Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote sensing of environment*, *129*, 122-131. https://doi.org/10.1016/j.rse.2012.10.031

[25] Boschetti, L., Stehman, S. V., & Roy, D. P. (2016). A stratified random sampling design in space and time for regional to global scale burned area product validation. Remote sensing of environment, 186, 465-478.

detected within the cluster (based on the Harvests layer created in Step 7 of Section 4.1.6.3). If applying NLCD for forest cover stratification, this will likely produce 8 strata total: Deciduous Forest with harvest, Deciduous Forest without harvest, Evergreen Forest with harvest, Evergreen Forest without harvest, Mixed Forest with harvest, Mixed Forest without harvest, Woody Wetlands with harvest, and Woody Wetlands without harvest. Each cluster shall be assigned to exactly one stratum.

- A simple random sample of the defined clusters in each stratum is performed. Model approvals for an individual GHG project must collect 30 samples per stratum. Regional model approvals must collect a number of samples per stratum based on the stratum's total size, at a rate of 30 samples per 70,685 square miles (i.e., the area of a 150-mile radius circle), or 0.000424 per square mile, rounded up.
- The entire area of the target population (e.g., non-federally owned forestland) of each sampled cluster is digitized into polygons of two classes: harvests and non-harvests. Areas outside the target population do not require polygons to be digitized.

- Imagery should have a spatial resolution of 2 meters or finer[26] and a temporal resolution of 1 year or less. However, if such imagery is unavailable for the given geography, it must minimally be of higher spatial resolution than the datasets used by the forest loss models (if the forest loss model utilizes imagery).[27] If the forest loss model uses imagery with a spatial resolution of 2 meters or finer, the same imagery can be used for visual interpretation. The publicly available imagery from the National Agricultural Imagery Program (i.e., NAIP, which has a temporal resolution of three years) may be used if imagery of the sampling frame was collected within one year of the end of the defined lookback period.

Both types of ground truth data sources (i.e., harvest data, imagery) may be utilized by model approvals for individual GHG projects and regional model approvals, and more than one ground truth data source may be used for a single model approval. The same ground truth data source(s), area of interest, and time period must be used for both the forest loss model and the combined GLAD and LCMS datasets (i.e., the Harvests layer; Section 4.1.6.3).

The minimum mapping unit rules described in Section 4.1.6.3 must be applied to harvest and non-harvest polygons from the ground truth data sources. In general, polygons less than 1 acre should be excluded, but polygons within 300 feet may be aggregated into multipart polygons before determining their size and whether they exceed the minimum mapping unit.

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[26] Neigh, C. S., Bolton, D. K., Williams, J. J., & Diabate, M. (2014). Evaluating an automated approach for monitoring forest disturbances in the Pacific Northwest from logging, fire and insect outbreaks with Landsat time series data. *Forests*, *5*(12), 3169-3198. https://doi.org/10.3390/f5123169

[27] Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E., & Wulder, M. A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote sensing of Environment*, *148*, 42-57. https://doi.org/10.1016/j.rse.2014.02.015

The scale applied for the model validation process (Options found in Section 7, above) determines the quantity of ground truth data required:[28]

- Model approvals for an individual GHG project (Option 1) using spatially explicit historical harvest data must identify 50 discrete harvest polygons (i.e., non-contiguous harvest polygons at least 1 acre in size each) and non-harvest polygons covering an area minimally equal to the area of the 50 harvest polygons. If using high-resolution imagery, a minimum of 30 samples per stratum must be collected. If using a combination of sources, both minimum thresholds (for harvest data and imagery) must be met, although the digitized polygons from high-resolution imagery may be counted towards the harvest data minimum thresholds (e.g., 50 discrete harvest polygons). Ground truth data must be obtained within the GHG project's 150-mile (or expanded as applicable; Section 4.1.1) buffer.
- Regional model approvals (Option 2) must employ a random sampling approach across the explicitly defined region, as specified for the high-resolution imagery data source (above). The minimum number of samples per stratum is based on the stratum's total size, at a rate of 30 samples per 70,685 square miles (i.e., the area of a 150-mile radius circle), or 0.000424 per square mile, rounded up. If spatially explicit historical harvest data is available for a certain sample, it may be used instead of (or in addition to) visually interpreting high-resolution imagery.

Once the minimum quantity of ground truth data has been collected, the resulting data layer constitutes the ground truth data source that may be used to assess model performance.

7.2 Model Performance Assessment

The model's performance assessment shall follow a post-hoc bootstrapping validation approach.[29] [30] The ground truth data is randomly resampled with replacement across multiple iterations. Each resample size should equal the size of the total available ground truth data. There must be at least one thousand iterations.[31] In each iteration, the results of the harvest model must be compared with the ground truth data within the resampled areas.

[28] Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E., & Wulder, M. A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote sensing of Environment*, *148*, 42-57. https://doi.org/10.1016/j.rse.2014.02.015

[29] Tibshirani, R. J., & Efron, B. (1993). An introduction to the bootstrap. *Monographs on statistics and applied probability*, *57*(1), 1-436. https://doi.org/10.1201/9780429246593

[30] Hastie, T. (2009). The elements of statistical learning: data mining, inference, and prediction. https://doi.org/10.1007/978-0-387-84858-7

[31] Davison, A. C., & Hinkley, D. V. (1997). *Bootstrap methods and their application*. Cambridge university press. https://doi.org/10.1017/CBO9780511802843

For each iteration, projects must then determine the following four instances, expressed in terms of the proportion of each iteration's respective sampled area:

- True Positives (TP): Proportion of the total resampled area correctly predicted as harvested.
- True Negatives (TN): Proportion of the total resampled area correctly predicted as non-harvested.
- False Positives (FP): Proportion of the total resampled area incorrectly predicted as harvested.
- False Negatives (FN): Proportion of the total resampled area incorrectly predicted as non-harvested.

Next, the following metrics are produced for each iteration for the purpose of publicly reporting model performance and, in the case of F1 score, to determine whether the project's model is approved for use.

Equation 7: Overall Accuracy

$$Overall\ Accuracy = \frac{(TP + TN)}{(TP + FP + TN + FN)}$$

WHERE

$Overall\ Accuracy$	Proportion of area (both harvested and non-harvested) correctly predicted.
TP	True Positives. Proportion of area correctly predicted as harvested.
TN	True Negatives. Proportion of area correctly predicted as non-harvested.
FP	False Positives. Proportion of area incorrectly predicted as harvested.
FN	False Negatives. Proportion of area incorrectly predicted as non-harvested.

Equation 8: Precision

$$Precision = \frac{TP}{(TP + FP)}$$

WHERE

$Precision$	Proportion of area predicted as harvested that was harvested.
TP	True Positives. Proportion of area correctly predicted as harvested.

FP	False Positives. Proportion of area incorrectly predicted as harvested.

Equation 9: Recall

$$Recall = \frac{TP}{(TP + FN)}$$

WHERE

Recall	Proportion of harvested area that was correctly predicted as harvested.
TP	True Positives. Proportion of area correctly predicted as harvested.
FN	False Negatives. Proportion of area incorrectly predicted as non-harvested.

Equation 10: F1 Score

$$F1\ Score = \frac{(2 \times Precision \times Recall)}{(Precision + Recall)}$$

WHERE

F1 Score	Harmonic mean of precision and recall.
Precision	Proportion of area predicted as harvested that was harvested.
Recall	Proportion of harvested area that was correctly predicted as harvested.

After the instances and metrics are calculated for each iteration, the project must report the summary of these statistics. First, an error matrix must be constructed that reports the mean of all iterations' comparisons, organizing the four instances according to Table 5:

Table 5: Error matrix for model performance assessment

		PREDICTED	
		HARVESTED	NON-HARVESTED
OBSERVED	HARVESTED	TP	FN
	NON-HARVESTED	FP	TN

Following the construction of the error matrix, the mean and distribution of each metric should be reported, accompanied by the respective 95% confidence interval (2.5th percentile and 97.5th percentile).

The same assessment method must be repeated with the combined GLAD and LCMS dataset, minus areas of natural disturbance or less than a minimum mapping unit of 1 acre (i.e., the Harvests layer; Section 4.1.6.3), producing an error matrix that reports the mean of all iterations' comparisons and a mean F1 score metric (Equation 13) and its accompanying 95% confidence interval (2.5th percentile and 97.5th percentile). Other metrics (e.g., overall accuracy) are not required for the combined GLAD and LCMS datasets. The same ground truth data source(s), methods, area of interest, time period, and randomly resampled ground truth data (i.e., iterations) must be applied. Prior to performance assessment, areas of natural disturbance and areas less than a minimum mapping unit of 1 acre must be removed from the GLAD and LCMS dataset outputs.

Next, the model's mean F1 score is evaluated in relation to the mean F1 score of the combined GLAD and LCMS datasets to determine whether the model is approved for use. For the project's model to be approved, its mean F1 score must be equal to or greater than mean F1 score of the combined GLAD and LCMS datasets.

If the project's model detects and classifies forest loss into distinct types, the overall accuracy, precision, recall, and F1 score and their respective 95% confidence intervals may be reported for each harvest type. All areas of forest loss identified by the model must be aggregated before conducting the F1 score comparison with GLAD and LCMS.

7.3 Area Correction

Once a model is approved for use, it must then be demonstrated that any potential classification error[32] is either accounted for through a discount or is conservative to disregard. An area-corrected proportion of harvested area is calculated and evaluated. If the area-corrected proportion of harvested area is greater than the custom model's predicted proportion of harvested area, then area correction can be conservatively disregarded and no area correction is applied. Otherwise, an area correction factor is calculated and applied in the final calculation of Harvest Intensity for the selected comparable property identified as harvested by the custom model to ensure that Harvest Intensity is not overestimated.

Equation 11: Area Correction Factor

$$\textbf{if} \left[\left(\text{Prop}_{\text{Harvested}} \times \left(\frac{\text{TP}}{\text{TP}+\text{FP}}\right)\right) + \left(\text{Prop}_{\text{Non-harvested}} \times \left(\frac{\text{FN}}{\text{TN}+\text{FN}}\right)\right) \geq \text{Prop}_{\text{Harvested}}\right] \textbf{then } \text{AreaCorrection} = 1$$

$$\textbf{else}$$

$$\text{AreaCorrection} = \frac{\left(\text{Prop}_{\text{Harvested}} \times \left(\frac{\text{TP}}{\text{TP}+\text{FP}}\right)\right) + \left(\text{Prop}_{\text{Non-harvested}} \times \left(\frac{\text{FN}}{\text{TN}+\text{FN}}\right)\right)}{\text{Prop}_{\text{Harvested}}}$$

WHERE

AreaCorrection	Area correction factor.
$\text{Prop}_{\text{Harvested}}$	Proportion of the sampling frame's total area predicted as harvested by the custom model.
$\text{Prop}_{\text{Non-harvested}}$	Proportion of the sampling frame's total area predicted as non-harvested by the custom model.
$\left(\frac{\text{TP}}{\text{TP}+\text{FP}}\right)$	The fraction of True Positives divided by the sum of True and False Positives.

[32] Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V., Woodcock, C. E., & Wulder, M. A. (2014). Good practices for estimating area and assessing accuracy of land change. *Remote sensing of Environment*, *148*, 42-57. https://doi.org/10.1016/j.rse.2014.02.015

$\left(\frac{FN}{TN + FN}\right)$	The fraction of False Negatives divided by the sum of True and False Negatives.

The area correction discount factor must be calculated for each comparable properties analysis. The result of Equation 14 is recorded in Table 1 of the Harvest Intensity Calculations worksheet. It is then applied in Table 2, where harvested acres are accordingly reduced prior to calculating the selected comparable property's Harvest Intensity.

7.4 Percent Biomass Removed per Acre

This tool does not provide an approval framework to validate custom models that predict percent biomass per acre at the pixel-level. However, projects using an approved custom model that identifies harvested areas (i.e., custom change detection models) must apply the guidelines found in this section to ensure that harvested area is weighted appropriately in the calculation of Harvest Intensity. Per Section 6.1, the approved default methods used by this tool's example demonstration (i.e., using GLAD and LCMS) assume the percent biomass removed per acre to be 100% based on the known limitations of GLAD and LCMS to detect partial harvests. If employing an approved custom forest loss model, partial harvests could be detected at a higher rate, resulting in a larger total harvested area.

For conservatism, any areas detected as harvested by both the custom model and the approved default datasets and methods utilized by this tool's example demonstration (i.e., the Harvests layer created in Step 7 of Section 4.1.6.3) must assume 90% biomass removed per acre. Any additional areas detected as harvested by the custom model (but not included in the Harvests layer created using GLAD and LCMS) must assume 50% biomass removed per acre.

Two steps in the comparable properties analysis refer to the percentage forestland harvested: applying the Harvest Occurrence eligibility criteria (final Steps 1 and 2, Section 4.1.6.4), and the outlier detection test (Section 5.3). The approved custom model's total harvested area (inclusive of areas assumed to be both 90% and 50% biomass removed per acre) should be used to calculate percentage forestland harvested in these steps.

7.5 Application of Custom Forest Loss Identification Models

Once a custom model has been approved per Section 7.2, it must be used throughout the comparable properties analysis, including during determination of eligibility, similarity matching, and outlier detection. However, since it may be computationally demanding and expensive to apply the custom model, Project Proponents may leverage the approved default methods used by this tool's example demonstration (i.e., GLAD and LCMS) to gain efficiencies when they can demonstrate an equivalent result.

For example, if the custom model's harvest layer integrates GLAD and LCMS in addition to areas detected solely by the custom model, the verifier can be reasonably assured that the custom model's harvest layer will always be equal to or greater than that of the approved default methods. One might infer that this allows the assumption that comparable properties which meet the harvest occurrence eligibility criterion (0.2% of forestland harvested per year; Section 4.1.6) using GLAD and LCMS would also be eligible when applying the custom model. However, forestland acreage is determined after the correction of forest cover stratification on recently harvested lands (Section 4.1.6.4), which therefore requires the custom model's harvest layer to be used when applying the harvest occurrence eligibility criterion. Harvested area-corrected forestland acreage is also needed for the geographic size eligibility criterion (Section 4.1.7) and several similarity criteria (Section 5.1), which complicates the process of using GLAD and LCMS for these steps.

To overcome this problem and still gain efficiencies in the application of the custom forest loss model, the Project Proponent may apply all eligibility criteria except harvest occurrence and geographic size (although prefiltering for geographic size could be applied; Section 4.1.3) to the initial list of comparable properties, followed by similarity matching (Section 5.2) using forestland acreage determined using GLAD and LCMS. This results in a list of potentially eligible comparable properties ranked by approximate similarity to the project property. The twenty approximately most similar comparable properties may be selected for application of the custom model, allowing for exact determination of eligibility and similarity ranking using the custom model's harvest layer on these properties. If more than three of the twenty approximately most similar comparable properties are deemed ineligible due to harvest occurrence or geographic size, they should be replaced by the next approximately most similar comparable properties for exact determination of eligibility and similarity ranking, repeating this process as necessary until at least eighteen eligible comparable properties are ranked by similarity using the custom model's harvest layer. All other comparable properties may determine eligibility and similarity criteria and ranking using GLAD and LCMS, and the normalization of similarity criteria (Step 1 of Section 5.2) may refer to the mean and standard deviation of similarity criteria calculated using both the custom model and the approved default methods. This process provides sufficient assurance that the final list of eight matched comparable properties is accurate without necessarily applying the custom model to determine exact eligibility and similarity on the entire list of potentially eligible comparable properties. This process is optional.

Regardless of any efficiencies gained during the determination of eligibility and/or similarity matching, the matched properties' percentage forestland acreage harvested during the lookback period must be determined using the custom model's harvest layer prior to outlier detection (Section 5.3), and all subsequent calculations of Harvest Intensity (Section 6) must also be determined using the custom model's harvest layer.

8 Reporting and Verification

8.1 Reporting

Whenever a comparable properties analysis is performed, the following reporting is required and must be provided as publicly available appendices to either the GHG Project Plan (at validation) or the Monitoring Report (later in the project term):

- The Comparable Properties Analysis Calculator,[33] including all inputs and calculations within each worksheet (Eligible Comparable Properties worksheet, Outlier Detection worksheet, and Harvest Intensity Calculations worksheet), resulting in the annual and cumulative Harvest Intensity baseline constraints and checks. Ownership details (including specific location) for properties owned by entities not participating in the GHG Project should be redacted;
- A Comparable Properties Analysis standard operating procedure (SOP) document, including the following:
    - The defined lookback period length, and its start and end years.
    - Description of the methods for defining properties, including:
        - Methods for defining project properties, including:
            - Description of polygons making up the project area and a summary of their ownership;
            - Number of management units created by combining polygons and a summary of their location and ownership;
            - If the project area is composed of multiple management units, describe the steps taken to evaluate similarity and group management units and the results of each step (Section 3.2.1). If hierarchical clustering was employed, provide the dendrogram (Section 3.2.1.1);
            - If one or more synthetic properties were defined (Section 3.2.1), describe the following characteristics for each synthetic property, including how they are determined:
                - Geographic size;
                - Ecological region(s);
                - Timber ownership class;
                - Proximity;
                - Absolute acreages of forest cover strata; and
                - Absolute acreages of canopy height classes.

[33] Found on this tool's website.

        - A list of all defined project properties.
    - For each project property, methods for defining comparable properties, including:
        - Description of the cadastral data source;
        - Description of the process of identifying ownership of parcels in the cadastral data;
        - Number of management units after combining parcels belonging to a single owner;
        - If verifiable evidence is provided to substantiate parcel combinations, describe the evidence; and
        - If a geographic distance rules is applied, define the rule and describe how it is applied.
- For each project property, description of the methods and data sources for applying eligibility criteria (Section 4.1) to determine eligible comparable properties, including:
    - Calculation of the threshold for percentage forestland harvested;
    - Calculation of the geographic size thresholds applied;
    - Ecological Region(s) applied;
    - Timber ownership classes applied;
    - Proximity buffer applied to the perimeter of the project property; and
    - Any steps taken in the case that too few eligible comparable properties are initially identified (e.g., expanding the buffer, different ownerships), their sequence, and the results of each step taken.
- Description of the methods and results for identifying harvests, including:
    - Methods and data sources for determining forest loss;
        - GHG Projects that utilize GLAD and LCMS following the methods of this tool's example demonstration need to declare that these data sources and methods are employed. Any deviations from the approved methods described by this tool must be described.
        - GHG Projects that utilize an internally-developed forest loss model must provide details that summarize the methodology, the type of algorithm used (e.g., random forest, support vector machine), the training or calibration data and processes, and the source data (e.g., satellite, Lidar, SAR, IFSAR). In addition, a metadata document with further details about the model methodology and assessment must be provided.
        - GHG Projects that utilize an externally-developed forest loss model (other than GLAD and/or LCMS) must provide documentation on the models utilized, including the authors, affiliation, model methodology, source data (e.g., satellite, Lidar, SAR, IFSAR), model performance, associated publication (if available), and other relevant details on the applicability for forest loss detection.
        - All GHG Projects that utilize a forest loss model other than GLAD and/or LCMS must describe the validation process and report model performance per Section 7, including:

        - Whether the model validation is for an individual project or a region. If for a region, a map of the explicitly defined region must be provided;
        - A detailed description of the ground truth data source(s), how it was collected, and how it conforms to Section 7.1;
        - The mean overall accuracy, mean precision, mean recall, and mean F1 score, and their respective 95% confidence intervals for the custom forest loss model;
        - Error matrix for the custom forest loss model;
        - Error matrix and mean F1 score for the combined GLAD and LCMS datasets, demonstrating equal or greater F1 score using the custom forest loss model;
        - The spatial and temporal resolution of the custom forest loss model;
        - A description of any post-processing or modeling performed to remove areas of natural disturbance and apply a minimum mapping unit (if applicable); and
        - The calculation of the area correction discount factor;
        - A summary of the custom model's harvest layer, including how many acres were detected as harvested by both the custom model and the approved default datasets and methods (i.e., GLAD and LCMS), how many acres were detected as harvested by the custom model alone, and the application of percent biomass removed per acre.
    - Methods for identifying and removing areas of natural disturbance, including the types of natural disturbance considered, data sources utilized, and the results of the removal process;
    - Methods for identifying matched properties subject to salvage harvests and a list of matched properties subject to salvage harvests. If salvage harvests are identified, provide imagery visually depicting each identified salvage harvest and a summary of the process and results of applying the safeguard to limit Harvest Intensity for properties subject to salvage harvests. If adjustments for undetected salvage harvests are applied, provide the results of the adjustment process for each adjusted property.
    - Methods for applying a minimum mapping unit and the substantiating evidence for the proposed threshold (if applicable); and
    - Imagery visually depicting identified harvests on the selected comparable property.
- Description of the methods and data sources for stratifying by forest cover. If using a stratification system other than NLCD, describe the evidence supporting the stratification system.
- The final number of eligible comparable properties after applying all eligibility criteria.
- Description of the similarity criteria applied and their associated data sources.
- Table(s) listing the similarity criteria and other attributes for each project property and its selected comparable property (similar to Table 4, above), including:
    - Percentage forestland acreage harvested during the lookback period;

- Similarity index (0 for the project property);
- Ownership description (including at minimum the timber ownership class and optionally other anonymized descriptive details);
- Distance from project property centroid (use 0 for the project property);
- Mean slope;
- Mean elevation;
- Aboveground biomass;
- Forestland acreage in each forest cover stratum;
- Percent forestland in each forest cover stratum;
- Forestland acreage in each canopy height class; and
- Percent forestland in each canopy height class.

8.2 Validation and Verification

The entirety of the comparable properties analysis is subject to validation and/or verification, but given its complexity, a risk-based approach may be applied when determining steps and datasets to inspect more closely, as informed by project reporting in the Comparable Properties Analysis Calculator and the Comparable Properties Analysis SOP document.

All underlying source material used to identify and match comparable properties must be supplied to verifiers. However, if replication of results (for each interim step as well as the final Harvest Intensity constraints) is not possible due to differing data sources or other limitations, verifiers may strategically review the project's data sources, data management systems, and data processing steps to reach a reasonable level of assurance. When validating and/or verifying the spatial extent of properties not participating in the GHG Project, discrepancies less than 1 acre are generally deemed low risk and acceptable, unless the verifier has reason to believe that the downstream impact on the total Harvest Intensity constraint for the stratum may shift more than 0.5%. Verifiers should consider discrepancies and their impacts cumulatively.

When validating and/or verifying a custom forest loss identification model (Section 7), in addition to any other activities needed for reasonable assurance, verification should minimally include the following checks. Ground truth data should be thoroughly vetted, and if high-resolution imagery was digitized, the digitization step should be inspected for replicability and non-bias. The flow of data in the model performance assessment must be traced, and all metrics must be recalculated. The calculation of and application of the area correction discount factor must be replicated, and the resulting harvest layer must be verified to ensure proper application of percent biomass removed per acre. Verifiers may direct questions to the model developer as part of their process.

This tool's example demonstration is one approved method to perform a comparable properties analysis utilizing ArcGIS Pro, but other methods and GIS software may be utilized. When evaluating other methods and software, verifiers should evaluate the intention and sequencing of data processing steps to determine whether sufficient attention has been paid to achieve reasonably similar results. These results do not need to be directly compared with results of the approved method described by this tool's example demonstration if reasonable assurance can be reached through other means.

Definitions

Commercial Harvesting	Any type of harvest producing merchantable material at least equal to the value of the direct costs of harvesting.
Harvest Intensity	For the purposes of this document, percent biomass removed per acre per year, relative to a property's relevant stratum size.
Management Unit	A discrete area where timber harvest decision-making and resources are considered to achieve management (e.g., revenue) goals. Management units may be composed of one or more parcels.
Parcel	A portion of land with boundaries defined for the purpose of tax assessment.
Professional Forester	An individual engaged in the profession of forestry. If a project is in a jurisdiction that has professional forester licensing laws, the individual must be credentialed in that jurisdiction.[34] Otherwise, the individual must be certified by the Society of American Foresters[35] or Association of Consulting Foresters[36] with multiple years of professional experience in the state or region.
Property	The basic unit to which a comparable properties analysis is applied. A property within the project area (i.e., a project property) may comprise one or more management units. A property outside the project area (i.e., a comparable property) always equals one management unit.
Ton	A unit of mass equal to 1,000 kg.

[34] For projects located in multiple jurisdictions with professional forester licensing laws, the individual must be credentialed in at least one of the jurisdictions.

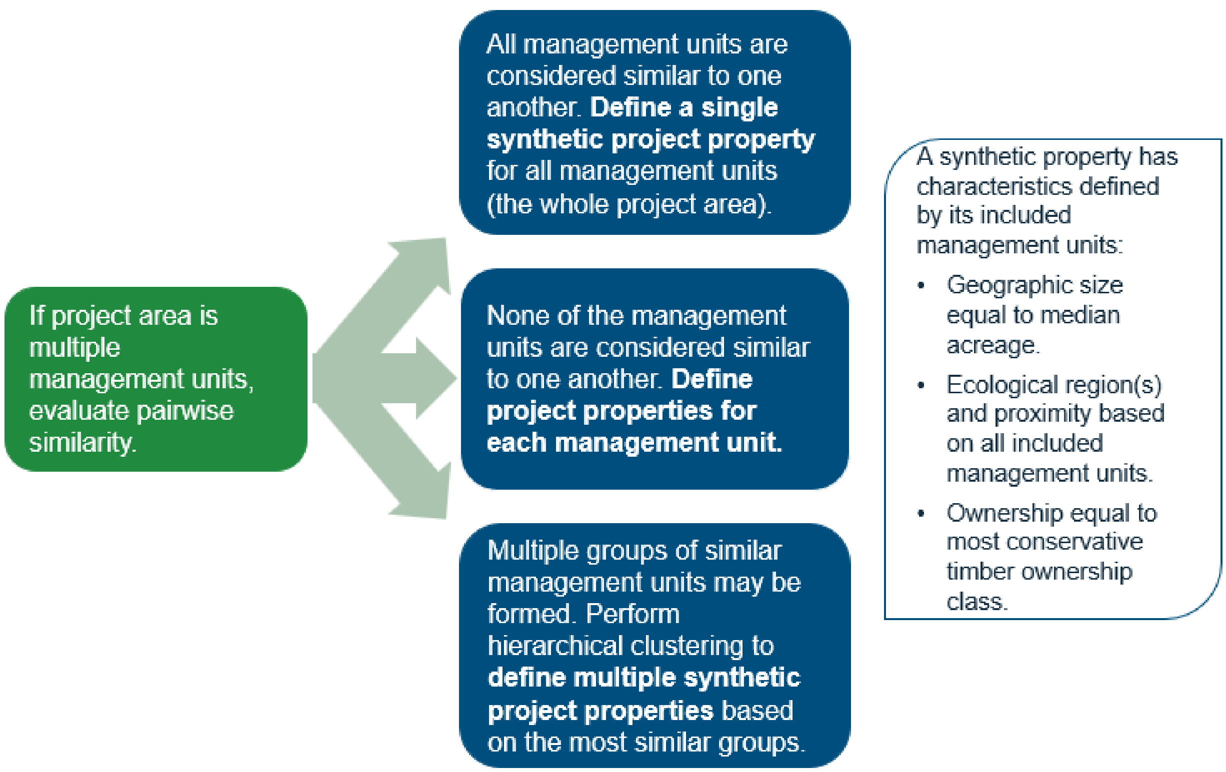
[35] https://www.eforester.org/Main/Certification_Education/Certified_Forester/Main/Certification/Certification_Home.aspx?hkey=53f11286-5500-4c13-a371-251dd0df0d7a

[36] https://www.acf-foresters.org/

Appendix A: Grouping into Synthetic Project Properties

This appendix describes the requirements and steps for defining project properties (Section 3.2) when the project area is composed of multiple management units. Management units must be evaluated in relation to one another to determine whether management units are required to be grouped into one or more synthetic project properties. Grouping management units into synthetic project properties provides a pathway to perform a single comparable properties analysis that is justifiably representative of multiple management units. Depending on the characteristics of the management units, either all, some, or no management units may be grouped into one or more synthetic project properties.

Figure 20: Defining project properties from multiple management units



A.1 Synthetic Project Properties

Synthetic project properties shall have the following characteristics:

- Eligibility criteria (Section 4.1) determined as follows:
  - Geographic size equal to the median management unit forestland acreage.
  - Ecological region(s) as determined for all the included management units.
  - Ownership equal to the most conservative timber ownership class of all the included management units.
  - Proximity as determined for all the included management units.
- All similarity criteria (Section 5.1) as determined for all the included management units, with the following exceptions:
  - Absolute acreages of forest cover strata must be proportionally determined using the forestland acreage of the median management unit. For example, the absolute acreage of the Deciduous Forest stratum must equal the percent acreage of the Deciduous Forest stratum (for all the included management units) multiplied by the forestland acreage of the median management unit.
  - Absolute acreages of canopy height classes must be proportionally determined using the forestland acreage of the median management unit.

A.2 Pairwise Similarity

To determine whether management units must be grouped into a synthetic project property, a subset of this tool's eligibility criteria for comparable properties (Section 4.1) shall be applied to the management units in a pairwise manner. Each management unit grouped together to form a synthetic project property must demonstrate similarity with all other management units within the group according to the following specifications. Once all project properties' Harvest Intensity constraints have been calculated, project-level stratum-specific Harvest Intensities are calculated by averaging all properties' Harvest Intensities, weighted by each property's contribution to the total project-level stratum acreage.

To be considered similar, management units must:

- **Geographic Size:** Contain forestland acreage meeting the following specifications:
  - If a management unit is greater than or equal to 4,000 acres, all other management units must be:
    - At least 25% of the forestland acreage of the management unit;

    - No greater than 250% of the forestland acreage of the management unit.
  - If the management unit is less than 4,000 acres, all other management units must be:
    - At least the lesser of either: 50% of the forestland acreage of the management unit, or 1,000 acres;
    - No greater than 250% of the forestland acreage of the management unit.
- **Ecological Region:** Be located within the same Ecological Region(s).[37]
  - A management unit located in multiple Ecological Regions is considered similar to other management units located in either respective Ecological Region.
  - Management units in other Ecological Regions can be considered similar when paired with verifiable evidence of a similar species and product mixture.[38]
  - Management units in other nations (e.g., Canada, Mexico) are deemed to be in different legal and economic environments, such that they are not considered similar.
- **Proximity:** Be located within a 150-mile buffer of the perimeter of the management unit[39] (Section 4.1.2).
  - Either aerial miles or road miles may be used.
  - If the Project Proponent can verifiably demonstrate the management unit's utilization of timber markets beyond the 150-mile buffer, that management unit's buffer may be expanded to match the distance to the furthest timber market utilized.

Optionally, the Project Proponent may employ ownership as another criterion for grouping management units into a synthetic project property. This creates ownership class-specific groups. Since synthetic project properties assume the most conservative ownership class of all its included management units, it is conservative to not use ownership as a grouping criterion, although its inclusion may result in more accurate Harvest Intensities for the included management units.

To be considered similar, management units may optionally:

- **Ownership:** Be owned (or timber controlled) by non-federal entities of the same timber ownership class (Section 4.1.5).

[37] Ecological Regions are spatially defined areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources (Omernik, 1987; Omernik and Griffith, 2014). The Level II Ecological Region delineation is required. Spatial files are available at: https://www.epa.gov/eco-research/ecoregions-north-america

[38] For example, forest type maps or other products showing similar timber types as the project property: https://data.fs.usda.gov/geodata/rastergateway/forest_type/

[39] 150 miles is a generalized maximum hauling distance based on: Pokharel, R., & Latta, G. S. (2020). A network analysis to identify forest merchantability limitations across the United States. *Forest policy and economics, 116*, 102181. https://doi.org/10.1016/j.forpol.2020.102181

- Assignment of timber ownership classes must conform to the United States Forest Service (USFS) Forest Inventory and Analysis (FIA) owner classification (Section 4.1.5; Table 1).
- If the timber rights of the management unit were recently acquired (within less than 5 years of the project Start Date), the timber ownership class of the previous ownership may be used.

To determine similarity between management units, Project Proponents must create pairwise matrices for all similarity criteria (i.e., minimally geographic size, ecological region, and proximity, and optionally ownership). This is an example of code for the R software environment that can be edited and used to create pairwise matrices and interpret the results. It requires a shapefile of the project area's management units.

Each matrix cell is assigned "Yes" or "No" to indicate whether or not the similarity criteria is met when evaluating the column's management unit using the row's management unit to define the similarity criteria (e.g., geographic size thresholds). Several outcomes are possible from this pairwise similarity comparison:

- All management units are considered similar to one another. Define a single synthetic project property for all of the management units (the entirety of the project area).
- None of the management units are considered similar to one another. Define project properties for each management unit.
- Multiple groups of similar management u nits may be formed. Perform hierarchical clustering to define multiple synthetic project properties based on the most similar groups, according to Section 3.2.1.1 below.
    - If the pairwise similarity comparison has clearly defined separate groups with no overlapping pairwise similarity, then hierarchical clustering may not be necessary, but the clustering section of the example R script may be used nonetheless to define project properties.

A.3 Clustering Management Units

Hierarchical clustering evaluates pairwise variables to determine the most similar groups. This statistical process may be performed with the R software environment or a similar software. The variables evaluated include the pairwise matrices for similarity criteria (created per Section 3.2.1) of geographic size, proximity (i.e., proportion of management unit within the 150-mile buffer), and ecological region as well as a new pairwise matrix for distance between centroids. Ownership may evaluated as a variable.

To prepare data for hierarchical clustering, the geographic size and proximity pairwise matrices for similarity criteria should be amended as follows. Since clustering favors smaller values, each matrix cell previously assigned No should be changed to the value 999 or some other extremely large value that forces the algorithm to never cluster that management unit pair together. Each matrix cell previously assigned Yes should have their values changed according to the following equations:

Equation 12: Geographic size pairwise similarity

$$\mathbf{S_{i,j}} = \left|\frac{\mathbf{Acres_i} - \mathbf{Acres_j}}{\mathbf{Acres_i}}\right|$$

WHERE

$S_{i,j}$	Pairwise matrix for the geographic size criterion for management units **i** and **j**.
$Acres_i$	Forestland acreage of management unit **i** (in acres).
$Acres_j$	Forestland acreage of management unit **j** (in acres).

Equation 13: Proximity pairwise similarity

$$\mathbf{P_{i,j}} = \mathbf{1} - \left(\frac{\mathbf{BufferAcres_{i,j}}}{\mathbf{Acres_i}}\right)$$

WHERE

$P_{i,j}$	Pairwise matrix for the proximity criterion for management units **i** and **j**.
$BufferAcres_{i,j}$	Forestland acreage of management unit **i** located inside of the 150-mile buffer of the perimeter of management unit **j** (in acres).
$Acres_i$	Forestland acreage of management unit **i** (in acres).

The ecological region similarity criterion is a binary response. In its pairwise matrix, each cell previously assigned No should be changed to the value 999, and each cell previously assigned Yes should be changed to the value 0.

A new pairwise matrix for distance must be created. The inclusion of distance as a variable in hierarchical clustering preferentially groups management units to nearer management units. The X and Y coordinates of each management unit's centroid are utilized in Equation 3, which includes division by twice the maximum distance of 150 miles (300 miles, or 482,803.2 meters) for value standardization.

Equation 14: Distance pairwise similarity

$$D_{i,j} = \frac{\sqrt{(x_i + x_j)^2 + (y_i - y_j)^2}}{482,803.2}$$

WHERE

$D_{i,j}$	Pairwise matrix for distance between management units **i** and **j** with centroids located at X and Y coordinates x_i and y_i and x_j and y_j, respectively.

After the four pairwise matrices have been created, sum them together. This creates a matrix that provides a single variable to be considered in the clustering process, and it shall be referred to as the similarity matrix. Any cell which includes a 999 in its sum should be changed to equal 999 again.

Hierarchical clustering assumes symmetry in pairwise relationships and only uses the lower triangular matrix, but the similarity matrix is asymmetrical (Table 6). To ensure that hierarchical clustering considers similarity between management units in both directions, the similarity matrix must be added to its transpose. This results in a symmetrical similarity matrix which is ready for clustering (Table 7).

Table 6: Example asymmetrical similarity matrix before adding to its transpose

	MGMT UNIT 1	MGMT UNIT 2	MGMT UNIT 3	MGMT UNIT 4	MGMT UNIT 5	MGMT UNIT 6	MGMT UNIT 7
MGMT UNIT 1	0	0.941	999	999	999	999	999
MGMT UNIT 2	0.625	0	999	0.618	0.498	0.635	0.459
MGMT UNIT 3	999	0.731	0	999	999	999	999
MGMT UNIT 4	999	1.107	999	0	0.484	0.217	0.330
MGMT UNIT 5	999	0.680	999	0.414	0	0.388	0.294
MGMT UNIT 6	999	0.961	999	0.202	0.407	0	0.262
MGMT UNIT 7	999	0.722	999	0.298	0.301	0.259	0

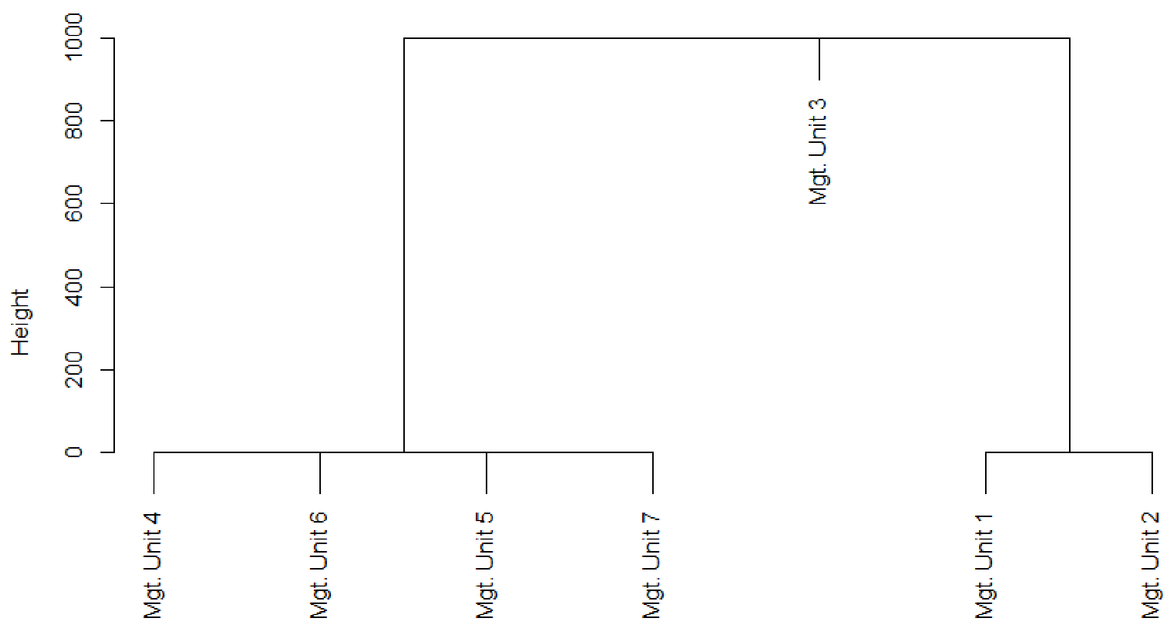
Table 7: Example symmetrical similarity matrix after adding to its transpose

	MGMT UNIT 1	MGMT UNIT 2	MGMT UNIT 3	MGMT UNIT 4	MGMT UNIT 5	MGMT UNIT 6	MGMT UNIT 7
MGMT UNIT 1	0	1.567	999	999	999	999	999
MGMT UNIT 2	1.567	0	999	1.725	1.677	2.231	1.639
MGMT UNIT 3	999	999	0	999	999	999	999
MGMT UNIT 4	999	1.725	999	0	0.898	0.419	0.628
MGMT UNIT 5	999	1.179	999	0.898	0	0.795	0.595
MGMT UNIT 6	999	1.596	999	0.419	0.795	0	0.520
MGMT UNIT 7	999	1.181	999	0.628	0.595	0.520	0

Hierarchical clustering should be performed using an agglomerative approach with complete linkage. In the example R code, this step is performed using the hclust() function, which is plotted to produce a dendrogram displaying the clustered results (Figure 20). Regardless of the software used, a dendrogram must be produced. The uppermost branch represents the most dissimilar clusters that should be used to define groups of management units.

Once management units have been clustered into groups, synthetic project properties can be defined based on the characteristics in Section A.1 using the management units in each group. If any management unit is not clustered with any others (e.g., Mgt. Unit 3 in Figure 20), it must define its own project property.

Figure 21: Example cluster dendrogram displaying management units grouped by similarity



Appendix B: References

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