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LANDISVIEW 2.0: An upgraded visualization and analytical tool for landscape modeling

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ABSTRACT

A major challenge in landscape modeling is to effectively visualize and analyze a massive amount of simulation outputs, which usually are in various raster and vector geospatial data formats. Because the task is often time-consuming and costly, available handy data viewers are limited. Yet, it is a useful tool for land managers to prepare and deploy their management plan in a landscape scale. Here, we upgraded our previous LANDISVIEW (version 1.0) to significantly enhance both visualizing and analyzing four major raster and vector geospatial data formats: ERDAS GIS/ASCII Raster (gis/.asc), ERDAS IMAGINE (.img) and Tagged Image (.tiff), which are the images formats widely used in remote sensing and landscape models (e.g., LANDIS). In addition, the version 2.0 software can serve as a converter for linking spatial data to other widely used landscape spatial analysis tools, including FRAGSTATS. Using this updated version 2.0, we were able to effectively assess a wildfire effect on forest structure and predict forest growth dynamics in responses to future wildfire and drought in northeastern California.

Software availability

Software name: LANDISVIEW 2.0
Contact: Dr. Weimin Xi (weimin.xi@tamuk.edu)
Year first available: 2019
Hardware required: IBM compatible PC
Operation System required: Windows 10
Program languages: C#, Net Framework 4.6
Availability: Downloadable from: https://sourceforge.net/projects/landisview-2-0

1. Introduction

Among the Landscape Disturbance and Succession Models (LDSMs), LANDIS (LANdscape DIsturbance and Succession) is a raster based, spatially explicit computer model designed to simulate forest succession and disturbances (wildfire, wind, insect outbreak, drought, land use, harvest and climate change) across broad spatial and temporal scales (Mladenoff, 2004, Xi et al., 2008, 2009a,b, 2016, Larocque et al., 2016). Since introduced in 1996, LANDIS has been widely used for evaluating forest dynamics, wildfire effects, and outcomes of various forest harvest scenarios (e.g., He et al., 2002, Scheller et al., 2007; Xi et al., 2009; Shang et al., 2012; Dai et al., 2016). Based on the need of evaluating forest dynamics and restoration strategies, we developed a software tool, LANDISVIEW 1.0, to visualize the large number of output files from LANDIS model in late 2000's (Birt et al., 2009). Over a 10-year period, computer performance, coding language and visualization methods have further improved, increasing the need for an upgrade. Therefore, an upgraded version of LANDISVIEW (version 2.0), is now available with better performance and expanded functions for both visualization and analysis of various raster and vector geospatial data.

There are several existing software with the function of processing raster and vector geospatial data formats. In addition to R and QGIS, some widely used software include:

- ArcMap: the main component of ESRI's ArcGIS suite of geospatial processing programs (commercial software ArcGIS Desktop), which is used primarily to view, edit, create, and analyze geospatial data (Environmental Systems Research Institute, 2020).
- ERDAS ER Viewer: a free desktop image viewer application and Microsoft Office Plugin offered within the Producer Suite of the

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Power Portfolio by Hexagon. It displays popular geospatial file types (Hexagon Geospatial, 2014).

- LandViz: an intuitive, browser-based tool that allows stakeholders to easily visualize and analyze model output. It is developed by Portland State University and Northern Research Station, USDA Forest Service to visualize the LANDIS-II output via web links (Gustafson et al., 2016).

Compared to other available geospatial data visualizing software, we developed LANDISVIEW as an open sourced geospatial image viewer designed to provide the most common functions of a LANDIS output viewer and geospatial data converter, to integrate key software features, and to enhance the data processing ability (Table 1).

In the previous version of LANDISVIEW (version 1.0), notable features include the ability to view, animate, and export a series of time-series data files in a customized sequence; a color palette for visualization; and convert ERDAS *.gis files into FRAGSTATS supported format (McGarigal et al., 2012). In the new version of LANDISVIEW 2.0, these basic features have been enhanced and a set of new features are introduced, including supporting more data formats: ERDAS IMAGINE (.img) format, Geotiff format (.tiff) and ESRI ascii raster format (.asc). One major improvement is that we developed a multiple window mode to compare multiple images and multiple scenario outputs simultaneously. New features include zoom control, highlight cell, customized color palette system, supporting xml preset, and map statistic table.

2. Structural and architectural design

LANDISVIEW 2.0 is designed as an open source software, which are free available to download. The source code and documentation are also available (https://sourceforge.net/projects/landisview-2-0) to the public. This is consistent with our belief from when we first developed LANDISVIEW in the late 2000's, that open code encourages open collaboration.

While model simulations normally produce massive amounts output, LANDISVIEW 2.0 is designed specifically for spatially explicit landscape modeling. We made particular effort in focusing on an intuitive, user-friendly image visualization experience. The basic workflow of LANDISVIEW is shown in Fig. 1.

LANDISVIEW 2.0 is written in C# program language (LANDISVIEW 1.0 is written in C++) for visualizing and animating 8-bit/16-bit ERDAS GIS Raster (.gis) and ERDAS IMAGINE (.img) files from LANDIS simulation and other LDSMs. The software used the GDAL (Geospatial Data Abstraction Library) developed by Warmerdam (2000) as an open source project for handling raster files.

2.1. Data classification

In the new version of LANDISVIEW, there are three types of input data supported: pure value data, which includes values for each map cell; pure image data, which includes color for each image pixel; and raster data, which mixes color and value. For each type of input data, a display strategy is defined for high performance, as shown in Fig. 2.

In the display design, detailed palettes are used for pure value data, which can set variety and flexible palette sets, and have better functionality for statistics; quick palette is used for mixed type data, which can set simplified color combinations and basic function; pixel control is used for pure image data, which can conduct color transformation at the pixel level. This strategy enables the quick response of different display processes (Kastuari et al., 2016).

2.2. Data structure

In forest disturbance and succession studies, it is essential to compare different periods in time for one disturbance or different disturbances occurring at the similar periods in time across a landscape. The ability to show multiple data in one window is essential, and a corresponding display strategy/mode should be designed. For this, the input data file is defined as a Map Data Series (MDS).

The Map Data Series (MDS) class is defined as a series of map data, including a map data list (with several map data), a statistics table and an information table of over-all map data, a palette for imaging and the corresponding legend. In the map data list, there are several map data, each of which includes map data, map image, a statistics table and an information table. The Map Data Series in LANDISVIEW 2.0 are defined in Fig. 3.

A data series class includes several map data, which can be organized by adding, removing, or sorting. After adding or removing a data file, a value dictionary is created for each of the map data, and the overall data series, palette, and map image is updated.

2.3. Palette

For visualizing a data series, we have enabled users the ability to assign specified colors for different values. This allows for the direct comparison between each cell for pure value data, further enhanced with supporting XML configuration. The window of palette system is shown as Fig. 4.

In the xml file, the syntax of the palette definition is shown as following:

<?xml version = "1.0″ encoding = "utf-8"?>
<Palettes>
…
<ClassifiedPalette>#d6a090,#fe3b1e,#a12c32,#fa2f7a,#fb9fda,#e61cf7,#992f7c,#47011f,#051155,#4f02ec,#2d69cb,#00a6 ee,#6febff,#08a29a,#2a666a,#063619,#000000,#4a4957,#8e7ba4,#b7c0ff,#fffff,#acbe9c,#827c70,#5a3b1c,#ae6507,#f7aa 30,#f4ea5c,#9b9500,#566204,#11963b,#51e113,#08fdcc</ClassifiedPalette>
…
<UniquePalette>#fffff,#ffd19d,#aeb5bd,#4d80c9,#e93841,#100820,#511e43,#054494,#f1892d,#823e2c,#ffa9a9,#5ae150,#ffe947,#7d3ebf,#eb6c82,#1e8a4c</UniquePalette>
…
</Palettes>

Table 1
Features of currently geospatial data visualizing software, including ArcMap, ERDAS ER Viewer, LandViz and LANDISVIEW.

Features	ArcMap	ERDAS ER Viewer	LandViz	LANDISVIEW	
Latest version	10.8	14.1	1.2	1.0	2.0
Release date	2019	2014	2018	2009	2019
Support format	Raster and vector	Raster	Raster	Raster (.gis)	Raster (.gis,.img, tiff)
View control	Zoom/Drag	Zoom/Drag	Zoom/Drag	x	Zoom/Drag
Palette control	Multiple palettes	x	Multiple palettes	Multiple palettes	Multiple palettes
Edit	Edit cellvalues	x	x	x	x
Statistic	Table/Chart	x	Chart	x	Table
Output format	raster, vector	Some raster	x	.fbt	.asc,.fbt
Export format	Image	Image	x	Image/Animation	Image/Animation
License	Commercial	Free	Open source	Open source	Open source

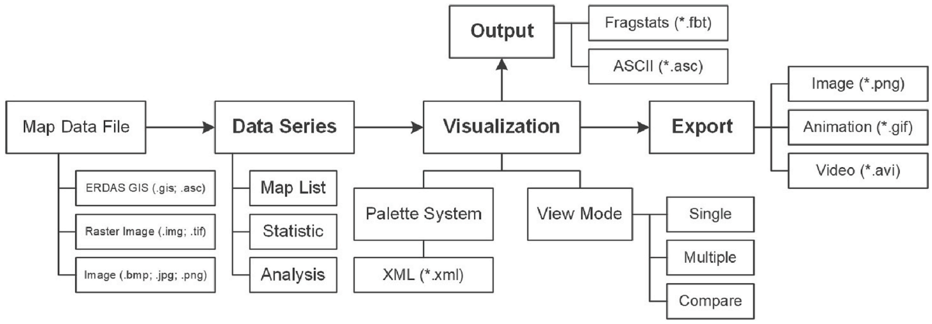


Fig. 1. A workflow shows the structure and architecture of the LANDISVIEW 2.0.

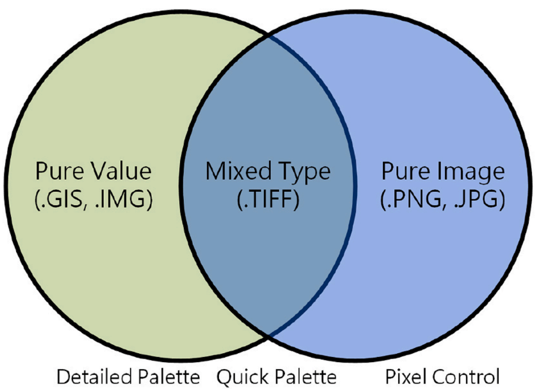


Fig. 2. Display strategy for different data type.

The palette system options include stretched, classified, and unique. In the xml configuration, the palette elements are defined as "StretchedPalette", "ClassifiedPalette", or "UniquePalette", in which the color combination is defined as a group of HEX values (RGB), separated by a comma. By this syntax pattern, users can modify the xml file to define new palettes. We developed a corresponding editor to support the palette system.

2.4. Display

The multiple data view mode is designed for displaying multiple data inputs (Fig. 5). Under this function, four data maps are displayed in one window in the same coordinates and location. In this mode, the same cell can be highlighted in each map display, and views can be scaled and moved simultaneously. To realize a quick response of user interface, map data class creates a snapshot when the palette is determined, which is saved as a map image. The logical relationship between single mode, multiple mode, and comparison mode is shown in Fig. 5.

2.5. Data process

The format of ".gis" is the only output format by LANDIS, but for further analysis and study, other format should be processed and converted, especially like ".fbt" (Fragstats) and ".asc" (EsriASCII). On the other hand, the animation of ecosystem evolution will enhance the effect of research of forest succession. In the new version of LANDIVIEW, map data can be exported or converted to three visualization formats and two data formats: Image (.png), Animation (.gif), and video (.avi); ASCII grids for compatibility with FRAGSTATS (.fbt), and ESRI ASCII raster format (.asc). FRAGSTATS is a spatial pattern analysis program for quantifying the structure of landscapes (McGarigal et al., 2012). This program simply quantifies the spatial heterogeneity of the landscape as represented in either a categorical map or continuous surface. The ESRI ASCII raster format is an ArcGIS supported format for cell-based or raster systems, which is a widely used for grid data. These functions are enhanced by optimizing the UI and supporting multiple view mode (Fig. 6).

All the selected files and formats can be exported by one click, and the data structure is determined by the data information table from the map data series. LANDISVIEW + FRAGSTATS also has different features from ESRI Spatial Analyst, shown as following Table 2:

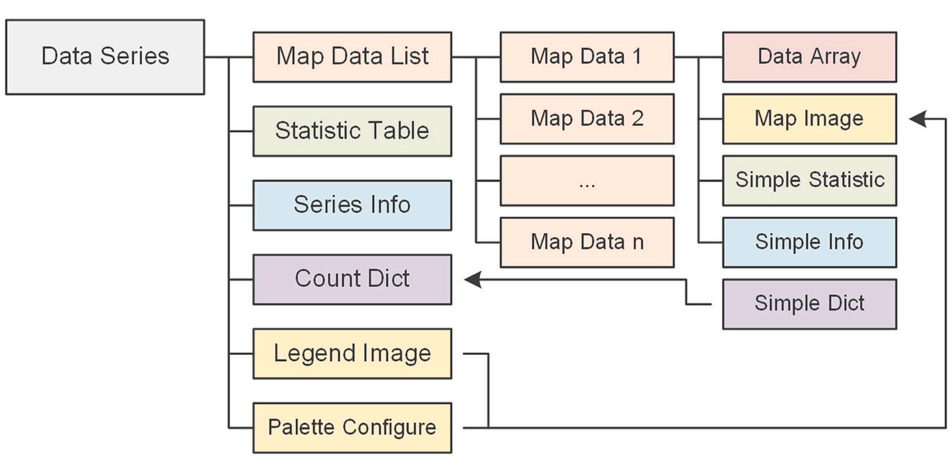


Fig. 3. A typical Map Data Series (MDS) class structure.

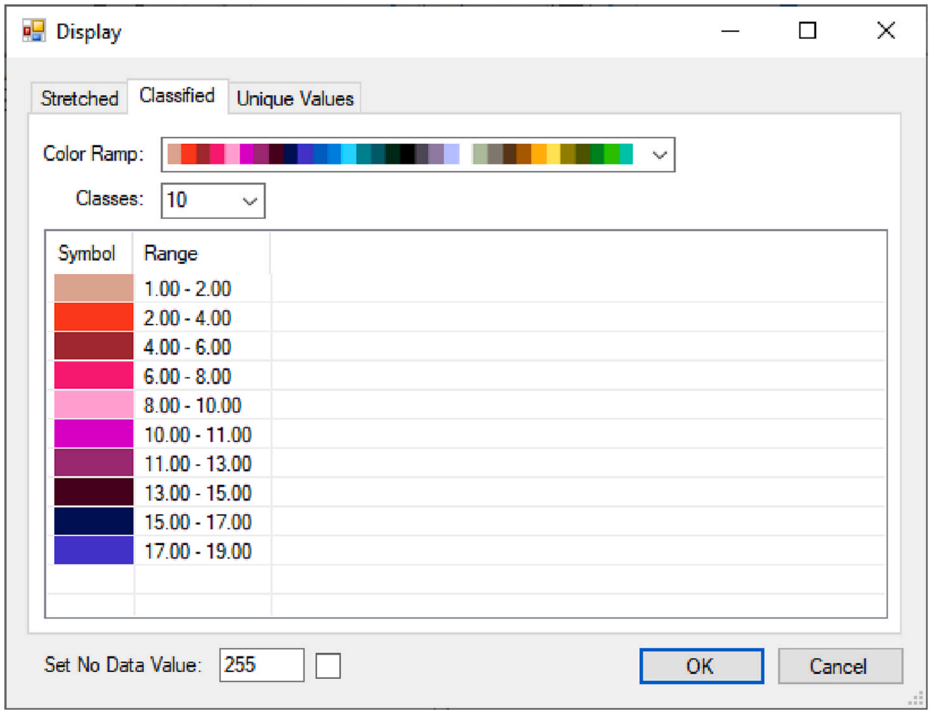


Fig. 4. An example of LANDISVIEW palette system.

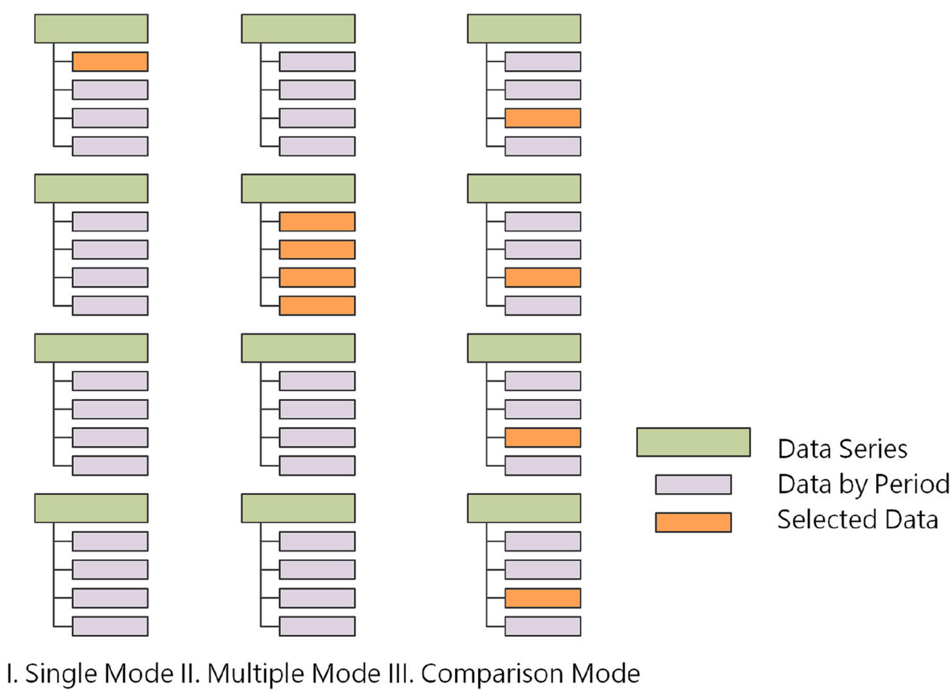


Fig. 5. The selected data in single mode, multiple mode and comparison mode.

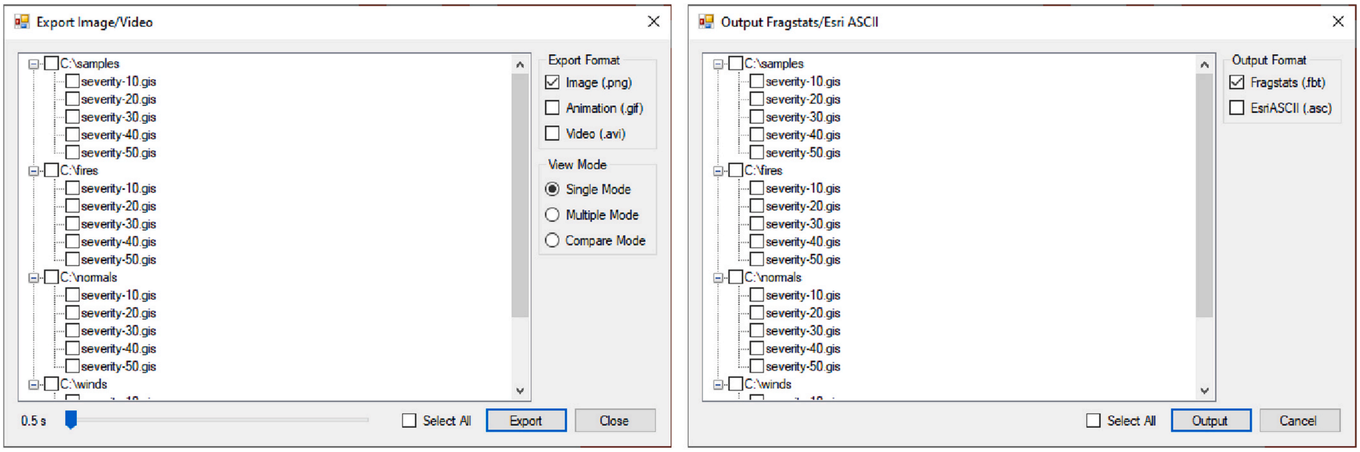
3. Software implications - visualization and analytical functions for landscape modeling

3.1. A case study –assessing the effects of wildfire on forest structure in northern California

3.1.1. Project overview

We provide here some examples of using LANDISVIEW 2.0 in our ongoing project to illustrate the key functions of the updated tool. The objective of our research project was to determine the forest structure that strikes an optimal balance of the forest ecosystems, between resiliency to wildfire and other biotic disturbances, maintaining wildlife habitat, and maintaining or increasing detrital carbon storage in the ponderosa pine, true fir, and mixed coniferous forests in the Lassen and Plumas National Forests in northeastern California (Fig. 7).

Lassen National Forest was established in 1905 with an area of 4331.53 km^2, covering a transition of Cascade Range in the north and Sierra Nevada in the south, while Plumas National Forest was



(a) Export Visualization formats (b) Convert Data Formats.

Fig. 6. Dialogue of landisview export/convert.

Table 2
Feature comparison between ESRI Spatial Analyst and LANDISVIEW and FRAGSTATS.

Type of analysis	ESRI Spatial Analyst	LANDISVIEW and FRAGSTATS
	Raster-based spatial analysis and modeling	Raster-based spatial pattern analysis
Key features	Query and data exploration Density mapping	Compute a wide variety of landscape metrics for categorical map patterns, including: Area/density/edge metrics
	Distance analysis	Shape metrics Core area metrics
	Surface interpolation	Isolation/proximity metrics
	Surface analysis	Contrast metrics
	Map algebra/Raster calculator	Contagion/interspersion metrics
	Local statistics	Connectivity metrics
	Neighborhood statistics	Diversity metrics
	Zonal overlay statistics	Converts ERDAS gis files into ASCII grids
	Multivariate statistics	Maps files can be viewed sequentially
	Hydrologic analysis	Maps can be generated as a movie or as an image file
	Raster generalization	
	Extensive customization options	
	Server-side processing	
Applications	Find suitable locations	Quantify spatial point patterns
	Calculate the accumulated cost of traveling from one point to another	Quantify linear network patterns
	Perform land use analysis	Quantify surface patterns
	Predict fire risk	Quantify categorical map patterns
	Analyze transportation corridors	Moving Window Analysis
	Determine pollution levels	Patch-corridor-matrix analysis
	Perform crop yield analysis	Habitat fragmentation analysis under alternative land management scenarios
	Determine erosion potential	Batch analysis
	Perform demographic analysis	
	Conduct risk assessments	
	Model and visualize crime patterns	

established in 1907 with an area of 4640 km ^{2} in the northern Sierra Nevada range of California. The United States Forest Service manages both national forests. The climate is a typical Mediterranean with hot, dry summers and cold, wet winters.

We quantify the effects of wildfire on forest structure using a combined analysis of field survey based forest stand data, and geospatial analysis in geographic information system (GIS). Forest stand conditions and wildfire severity were mapped based on fitted Landsat imagery and aerial images. In particular, we incorporate satellite imagery from multiple Landsat missions and National Forest Inventory and Analysis (FIA) forest plot data to understand the patterns, causes of, and consequences of biomass stock status and change, related to wildfires and drought.

We integrate LANDIS-II Model, climate and drought data to assess forest resilience, and scale-up these surveyed plot-level data into a GIS into the entire area to predict forest dynamics under varied restoration projects for all forests. We investigate how forest resilience may offer new contributions to forest management, in particular by identifying how it differs from earlier guiding paradigms. We study effects of wildfire and fuel-reduction treatments on forest structure and carbon dynamics and to evaluate using forest structure as a management tool in forest restoration projects.

3.1.2. Input maps for LANDIS-II simulations

We used the Ecological Subregions of the United States by USDA Forest Service Ecological Classification and Mapping Task Team (Bailey, 1995) (Fig. 8). LANDISVIEW 2.0 can easily display the ecoregions map (ecoregions.img), which includes 19 ecoregions in the study area. The View – Properties shows the basic information about the ecoregions, including raster information (e.g., columns and rows, cell size, and

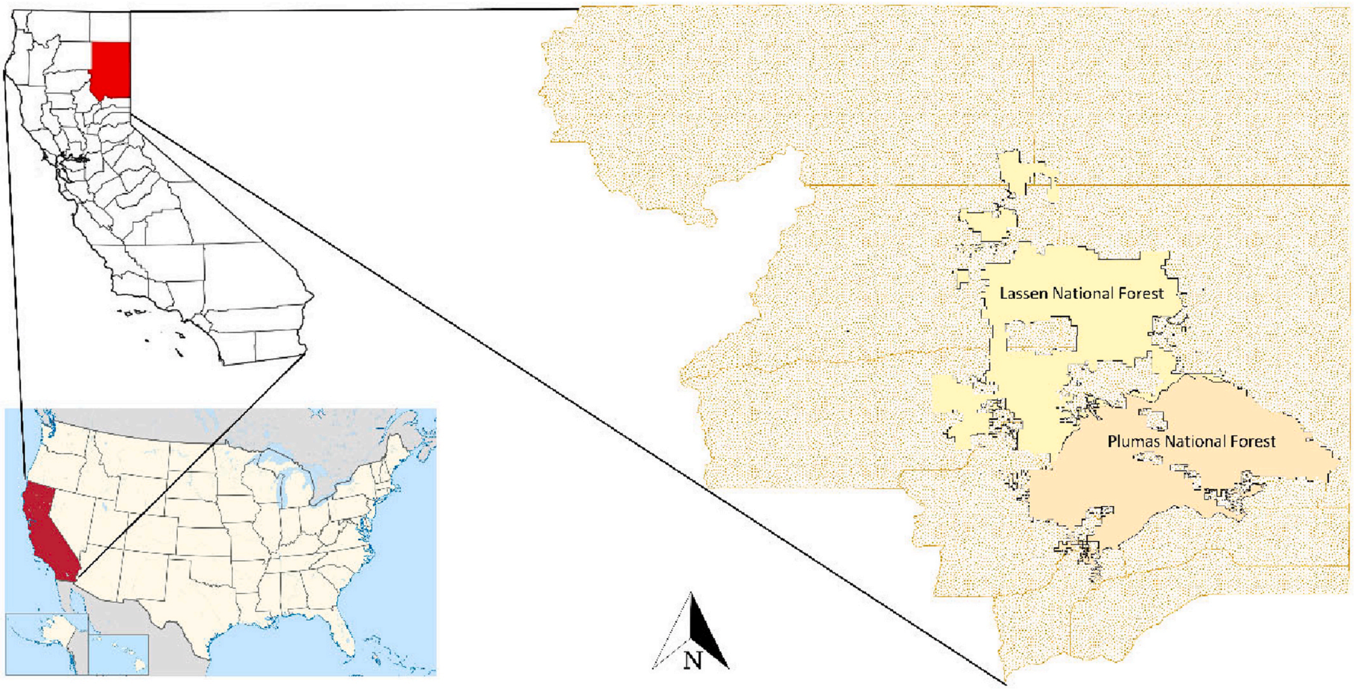


Fig. 7. A location map of the study area, including Lassen and Plumas National Forests in north California, USA.

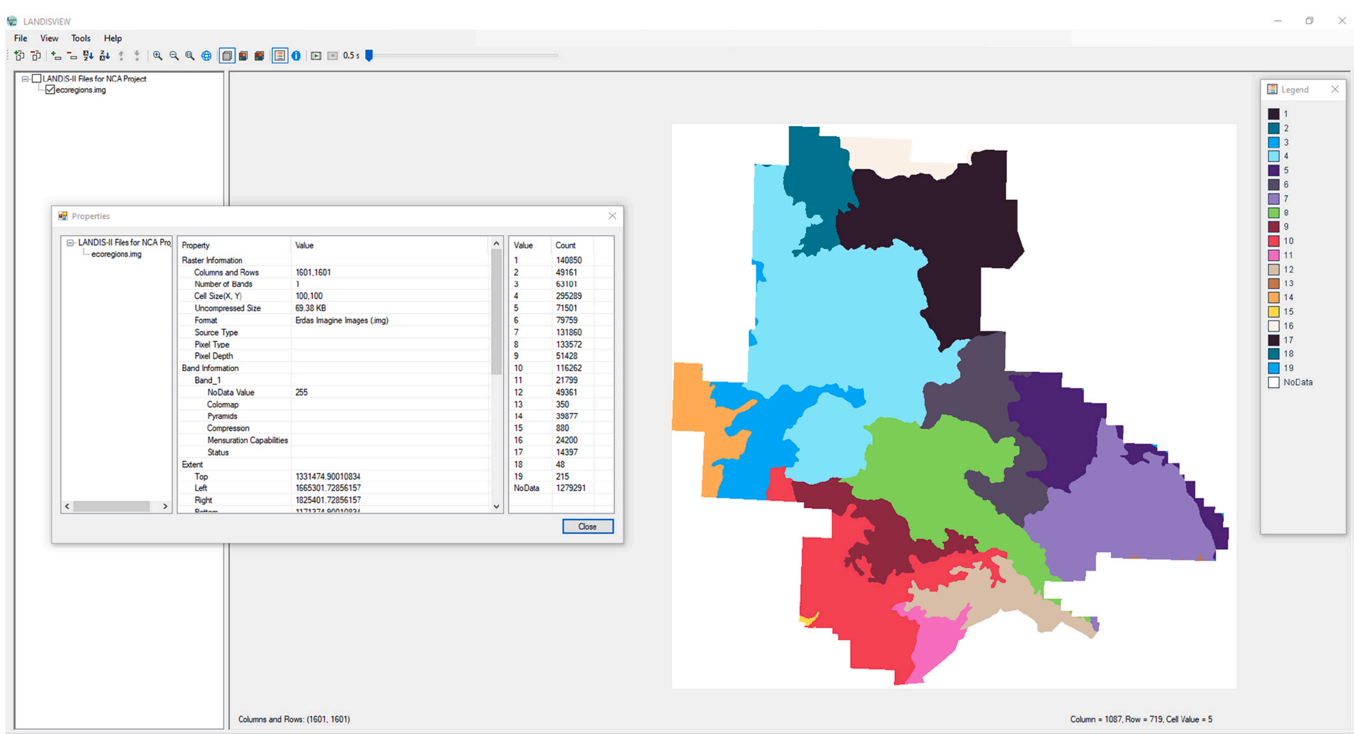


Fig. 8. Ecoregions based on subdivision by USDA Forest Service.

image format), extent, spatial reference and statistics.

The vegetation in the area was a typical mixed conifer forest. We used the R5 CALVEG (Existing Vegetation CALVEG, 2004, https://www.fs.usda.gov/detail/r5/landmanagement/resourcemanagement/?cid=stelprdb5347192) classification system by the Pacific Southwest Region (R5) Information Management staff to create initial communities map, including 94 vegetation types (Fig. 9). In total, 26 tree species were selected in the LANDIS-II simulation based on tree composition ranking in the FIA plots in the two national forests. LANDISVIEW 2.0 provides a user-friendly interface to present geospatial information of the initial communities (e.g., vegetation types), including raster information (e.g., columns and rows, cell size, and image format), extent, spatial reference and statistics (Fig. 9).

The multiple windows in LANDISVIEW 2.0 allow users to view major input images simultaneously (Fig. 10). For example, Fig. 10 shows the ecoregions map, initial communities map, the initial drought and initial

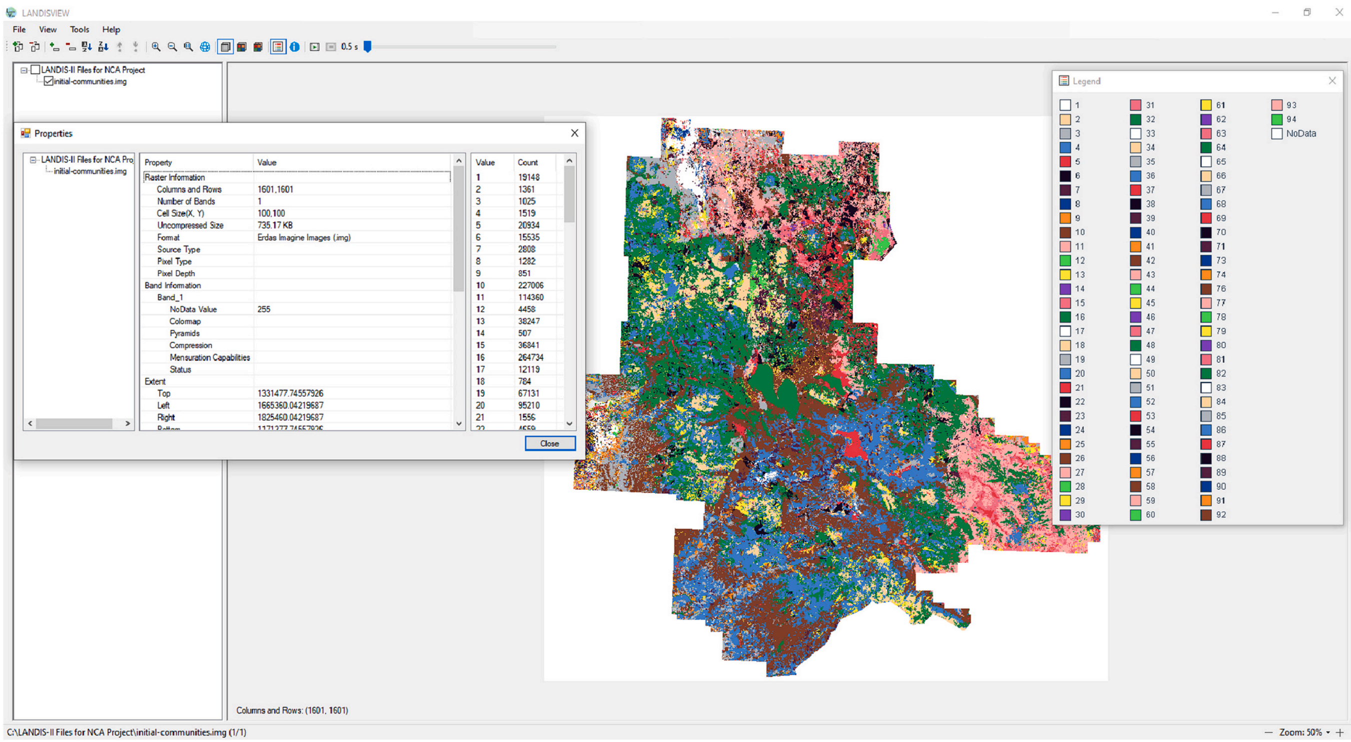


Fig. 9. Initial communities (vegetation types) shown in the LANDISVIEW 2.0.

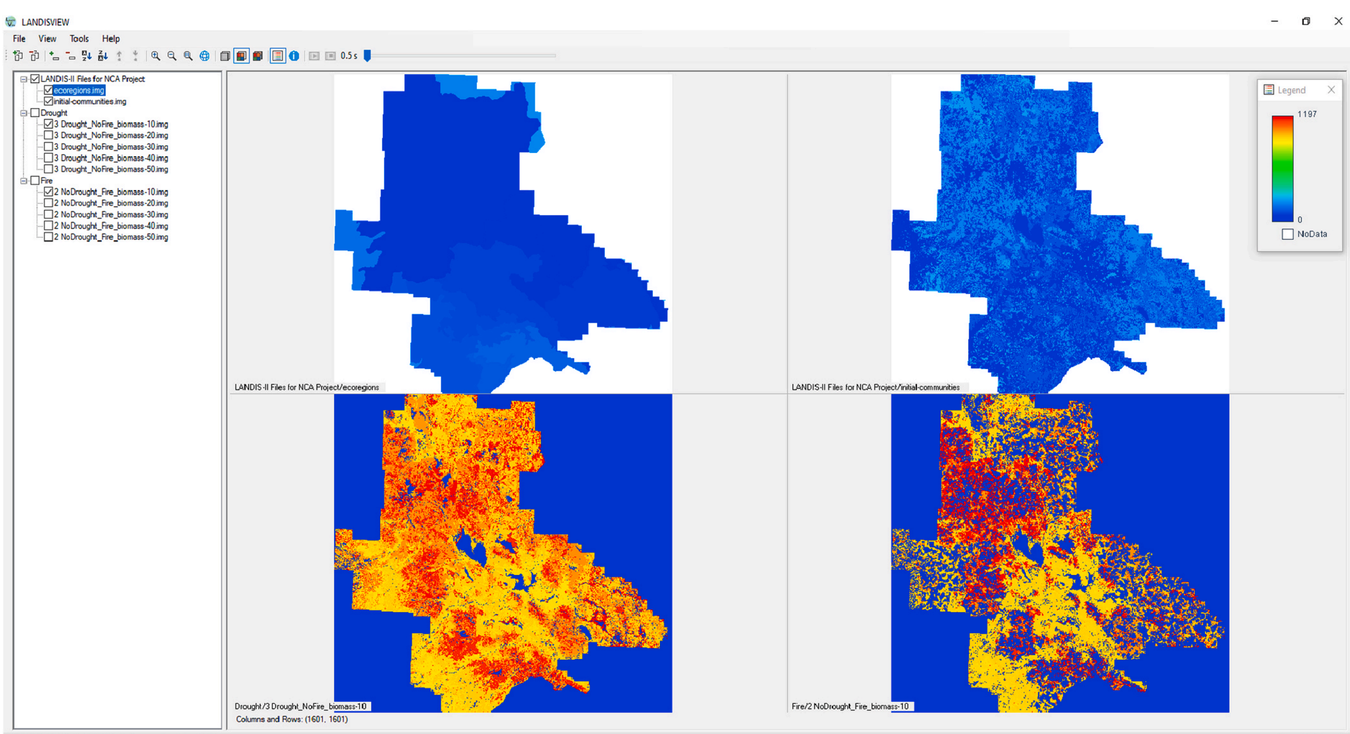


Fig. 10. Initial simulation maps for LANDIS-II simulations.

wildfire maps.

3.1.3. *Visualization of multiple biomass output maps from LANDIS-II simulations*

We developed four scenarios to examine the biomass changes for the future 50 years, 1) no wildfire and no drought, 2) wildfire without drought, 3) drought without wildfire and 4) both drought and wildfire. The multiple scenario display and animation allows us to simultaneously compare and view LANDIS-II biomass output maps side-by-side. This is especially useful when simulations from multiple scenarios are conducted and need to be visually compared (Fig. 11). These simulations support collaboration between scientists and managers in achieving

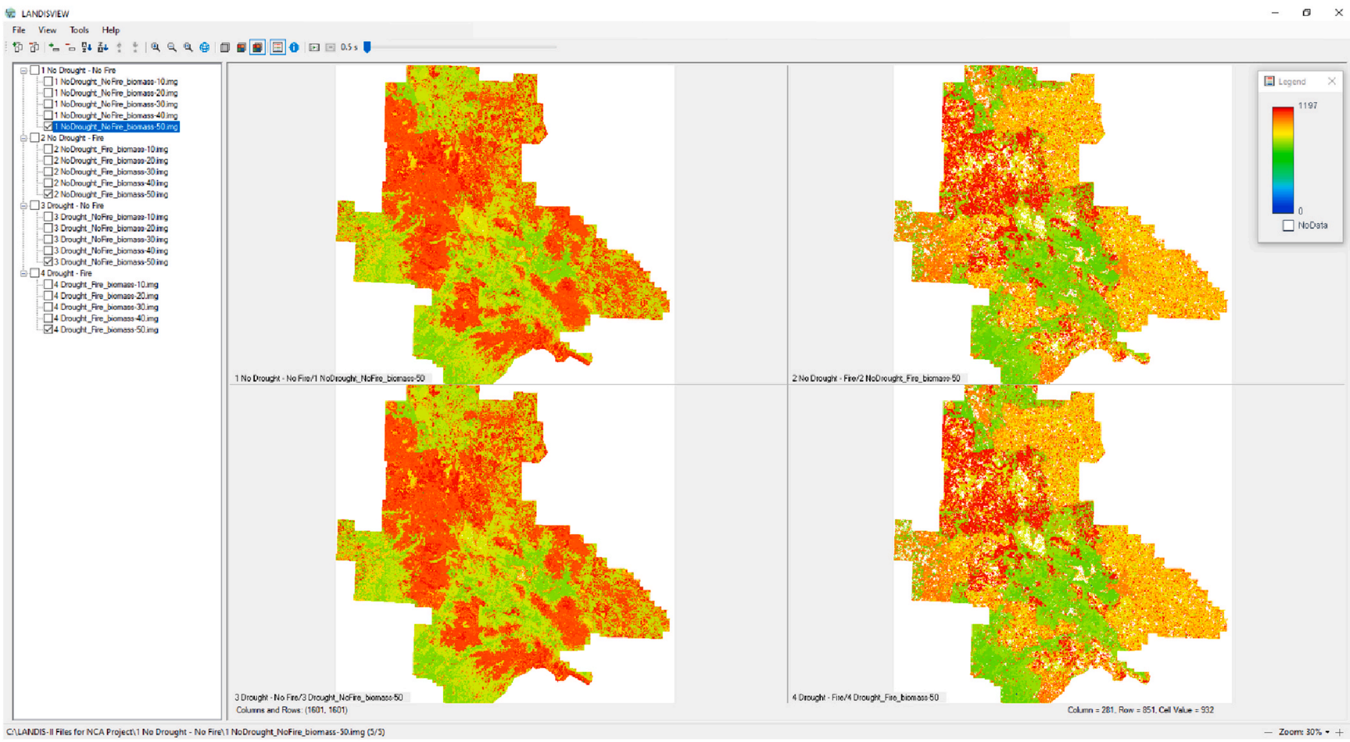


Fig. 11. Multiple scenario display and animation, including no wildfire no drought, wildfire without drought, drought without wildfire and both drought and wildfire four scenarios.

optimum forest structures. This understanding is essential for forest managers to achieve their management goals.

3.2. Broader implications

In addition to our applications, LANDISVIEW 2.0 has been used for LANDIS-II training workshops organized by the Institute for Applied Ecosystem Studies (IAES), Northern Research Station, USDA Forest Service. This tool was tested and used in several research projects in USA, Canada and China. The LANDISVIEW 2.0 software has been highlighted and linked by the following websites: LANDIS-II Model (http://www.landis-ii.org/tools/landisview) and NASA's Global Change Master Directory (https://cmr.earthdata.nasa.gov/search/concepts/C1214586381-SCIOPS).

3.3. Limitations and further improvement

A few current limitations and features could be enhanced in future versions of LANDISVIEW, which includes 1) slower response time when handling extremely large data files, 2) the analytical and statistical functions that could be further enhanced to meet users' needs, and 3) improved data-editing function. We will continue to improve the functions (3D visualization, support additional geospatial data formats, higher performance and analytical functions) of this software. Continuous user surveys are planned for better understanding and meeting user needs.

4. Concluding remarks

The work presented here is part of a larger effort to investigate the utility of landscape models as a decision-making tool for pre-disturbance impact analysis and post-disturbance restoration of forest landscapes threatened by various biotic and abiotic disturbances (Xi et al., 2008). This upgraded version of LANDISVIEW has added a new set of functions (multiple window animations etc.) for handling large quantities of ERDAS GIS Raster (gis/.asc) and ERDAS IMAGINE (img/.tiff) spatial image files, and has been shown as an effective processing-tool for ecologists, geographers, foresters, and modelers.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envsoft.2020.104849.

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