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Computer visualization of pre-settlement and current forests in Wisconsin

Andrew M. Stoltman, Volker C. Radeloff *, David J. Mladenoff

University of Wisconsin, Department of Forest Ecology and Management, 1630 Linden Drive, Madison, WI 53706, United States

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Abstract

A growing trend in public forest management is the inclusion of the public in the decision making process. Visual representations of the management process can assist in conveying complex management treatments. A second trend has been the promotion of biological diversity as a management objective. Ecosystem managers and restoration ecologists are using pre-settlement landscape patterns and forest conditions as a reference point to encourage the recovery of rare or extirpated species and habitat types. The problem is that information about pre-settlement conditions is limited. Our research goal was to visualize pre-settlement forests in Wisconsin and compare them with current forest conditions. Pre-settlement vegetation conditions were derived from computerized U.S. Public Land Survey records. Current forest conditions were derived from USDA Forest Service Forest Inventory and Analysis data. We used World Construction Set software (3D Nature, LLC) for the visualizations. Our results focus on ecosystems that are (a) still widespread but altered in structure and species composition (northern hardwoods communities) or (b) greatly diminished in extent (pine barrens communities). We found there are substantial visual differences between current and pre-settlement forests, most notably in species composition, density, and stand structural complexity. Our results highlight the potential of computer visualization as a tool to aid forest managers and restoration ecologists.

Keywords: Historic benchmark; Restoration; Visualization

1. Introduction

A growing trend in the management of public forest lands has been the integration of the public into the management process (Fedkiw, 1998). In the U.S., the general public has become an important part of the decision-making process since legislation in the 1970s allowed for more formalized and widespread public participation in national forest planning and management (Fedkiw, 1998). An internal memo from then chief of the USDA Forest Service states ''The Forest Service is committed to seeking greater public involvement in its decision making process; indeed, we welcome it'' (Cliff, 1970). During the formation of the Northwest Forest Management Plan in the 1990s, the USDA Forest Service received over 100,000 comments during the public comment stage (Proctor, 1998).

Increasing public participation in the management process, and increasing spatial and temporal scale of management considerations make it more important to visually demonstrate those options to the public. ''Visual assessment of the potential impact of a proposed plan or design is a crucial step for decision-making in environmental planning and management endeavors'' (Oh, 1994). Computer visualization is a tool that can translate complex quantitative information into a format accessible by non-experts (Sheppard, 1989). Visualization also helps experts and non-experts alike to integrate large amounts of data on different aspects of a forest. Through the 1990s, the technology to visualize forest stand and landscape conditions has grown significantly. Visualizations demonstrated the effects of logging and disturbance (Orland, 1994), and results of growth and yield modeling (McCarter, 1997), to compare different management tactics (McCarter et al., 1998; McGaughey, 1998) and to assess aesthetic impacts and public perception to stand conditions (Oh, 1994).

A parallel trend in forest management has been the promotion and maintenance of biological diversity (Millar et al., 1990; Probst and Crow, 1991; Kangas and Kuusipalo, 1993; Hunter, 1999). In order to attain this goal, some form of historical reconstruction of ecological conditions must be used as a reference point to compare current biotic communities with past communities, and to plan for future management (Swetnam et al., 1999; Foster et al., 1996; Cissel et al., 1994, 1999).

* Corresponding author. Tel.: +1 608 263 4349; fax: +1 608 262 9922.
E-mail address: radeloff@wisc.edu (V.C. Radeloff).

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One data source that has been used extensively to describe historical vegetation conditions in various areas of the U.S. is the original Public Land Survey records from the U.S. General Land Office (Finley, 1951; Bourdo, 1956; Kapp, 1978; Schulte et al., 2002). The Public Land Survey data have been used for a wide variety of applications including the examination of pre-settlement disturbance regimes (Lorimer, 1977; Kline and Cottam, 1979; Canham and Loucks, 1984; Grimm, 1984; Radeloff et al., 1998), landscape patterns (White and Mladenoff, 1994; Delcourt and Delcourt, 1996; Nelson, 1997; Manies and Mladenoff, 2000), and vegetation composition (Mladenoff and Howell, 1980; Iverson, 1988; Anderson, 1996; Radeloff et al., 1999). In general, the results of these analyses have been demonstrated using tabular formats or maps. What has been missing from these analyses is a visual representation of the ecosystems and processes they are attempting to describe.

Our goal was to develop a scientifically sound method to create visualizations of pre-settlement forests. We focused on forest types that are no longer extant in Wisconsin or have been greatly changed in composition, and compared pre-settlement visualizations with visualizations of current forest conditions.

2. Methods

2.1. Study area

Our study areas were in northern Wisconsin (Fig. 1), within the USDA Forest Service's Vegetation Province 212. Province 212, the Laurentian Mixed Forest Province, contains the northern regions of Minnesota, Wisconsin, and Michigan, as well as parts of New England. It is characterized by low relief with rolling hills. This province lies between the boreal forest and the broadleaf deciduous forest zones and is therefore transitional, consisting of mixed stands of coniferous and deciduous species (Keys et al., 1995).

In choosing representative sub-regions for visualization, we used the USDA Forest Service National Hierarchical Framework to select areas suitable in size to collect sufficient data points (Cleland et al., 1997). This framework was designed to classify areas ecologically on decreasing scales. At the regional scale, a 'province' represents an area on the order of 10s of 1000s of square kilometers. Beneath the province units are sections and subsections, with subsections representing from 10s of square kilometers to 1000s of square kilometers. Beneath the subsections are land type associations (LTAs) representing 100s to 1000s of ha (Cleland et al., 1997).

Two subsections of Province 212, 212Xe (Perkinstown End Moraine), and 212Ka (Bayfield Sand Plains), were selected due to their differing pre-settlement forest types; 212Xe being predominantly hemlock/northern hardwoods, and 212Ka being dominated by jack, red, and white pine (Schulte et al., 2002).

Both subsections have changed substantially over the last century. In the 1850s, the Perkinstown End Moraine contained northern hardwood species including eastern hemlock (*Tsuga canadensis*), sugar maple (*Acer saccharum*), and yellow birch (*Betula alleghaniensis*) along with many other species. The area was logged in the 19th century mainly for eastern white pine (*Pinus strobus*) of high value. By World War I, demand for hardwoods increased, and this area was again harvested, most often by clear cutting (Curtis, 1959). The Bayfield Sand Plains subsection, often referred to as the pine barrens, was originally a fire dominated ecosystem on very sandy soils with scattered stands of trees, mostly jack pine (*Pinus banksiana*), with some red pine (*Pinus resinosa*) and northern pin oak (*Quercus ellipsoidalis*) also present. The area was logged for red and white pine beginning around 1860, followed shortly by farming (Radeloff et al., 1999). The harvest of jack pine for pulpwood began around 1910 (Murphy, 1931). By 1930, logging, fires fueled by logging, slash, and agriculture had mostly removed any forest cover. Depletion of soil fertility caused farmers to

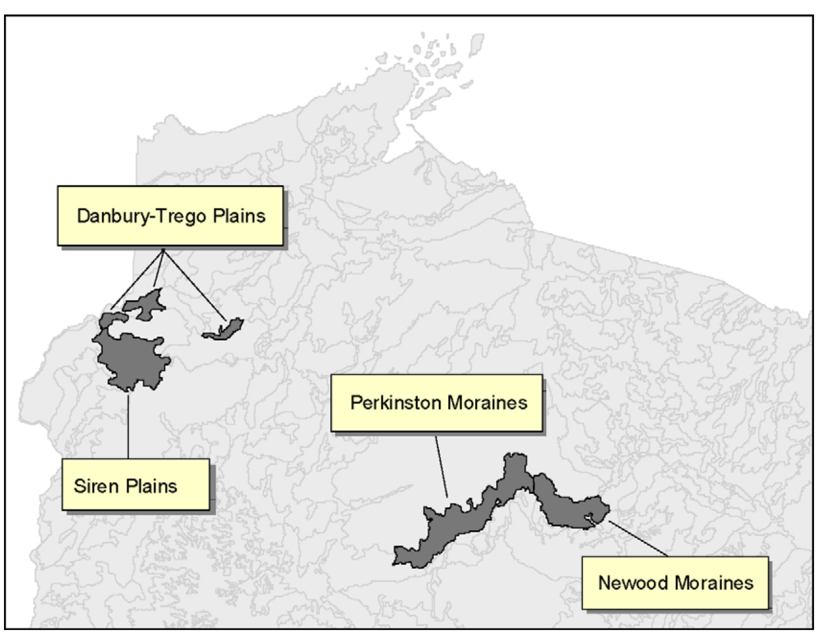

Fig. 1. Study area in northern Wisconsin, U.S.A.

Table 1
Description of the land type associations (LTAs) and their area (WDNR, 1999)

LTA	Description	Area (ha)
212Xe05 (Perkinstown Moraines)	The characteristic landform pattern is hilly collapsed moraine. Soils are predominantly well drained loamy soils over dense, acid sandy loam till	69,870
212Xe09 (Newood Moraines)	The characteristic landform pattern is rolling collapsed moraine with ice-walled lake plains common. Soils are predominantly moderately well drained sandy loam over dense acid sandy loam till	36,495
212Ka09 (Siren Plains)	The characteristic landform pattern is undulating outwash plain and lake plain complex. Soils are predominantly moderately well drained sand over outwash or clayey lacustrine	50,378
212Ka16 (Danbury-Trego Plains)	The characteristic landform pattern is undulating outwash plain with fans and stream terraces common. Soils are predominantly excessively drained sand over acid sand outwash	20,579

abandon the land during the 1930s (Radeloff et al., 1999). Also, beginning about 1930, fire suppression allowed for succession to occur and the area became mostly closed forest dominated by jack pine (Curtis, 1959).

Within each subsection, two LTAs were chosen to examine local forest variability (Table 1). Data were summarized within LTAs to ensure a sufficiently large number of data points from both current and pre-settlement data sources.

2.2. Data sources

We used the original Public Land Survey records from the U.S. General Land Office to construct visualizations of the pre-settlement forest conditions. The Public Land Survey was instituted by the U.S. government in the late 1700s to demarcate its territories for sale, grant, and settlement. The majority of Wisconsin was surveyed between 1832 and 1866 (Schulte and Mladenoff, 2001). The land was divided into a grid of (mostly) square townships (6 mi $\times$ 6 mi), made up of 36 individual square mile sections (Stewart, 1935). At each section corner and at the mid-point between section corners (quarter corners) a survey marker was placed, and two to four witness trees were identified and measured using diameter at breast height (DBH), plus their distance and direction from the corner, to document the section corners (Bourdo, 1956). Using witness tree data that had been collected by the surveyors, including species, quantitative information on the composition and structure of the pre-settlement forest types can be obtained (Bourdo, 1956). One limitation of the use of these data is that they are generally not applicable to small scales, and should not be used on areas less than 10,000 ha (Manies and Mladenoff, 2000). Witness tree data may also be affected by surveyor bias, such as preference for certain tree species or size classes (Bourdo, 1956). A detailed investigation of surveyor bias found that significant differences exist among surveyors in terms of tree species marked, but distances to witness trees were not significantly different among surveyors (Manies et al., 2001). It was thus concluded that while bias exists, it is overall fairly weak because surveyors were not inclined to travel far to reach preferred tree species (Manies et al., 2001). The analysis of larger areas will minimize surveyor bias as data from multiple surveyors were averaged.

Public Land Survey witness tree data from northern Wisconsin were transcribed into a geographical information system (GIS) database as a point coverage (Manies, 1997; He et al., 2000). We overlaid the individual land type association (LTA) boundaries and extracted all Public Land Survey data points in a given LTA. For our analysis, any points that were described as 'swamp', 'bog', 'bottom', or 'lake' were removed from the dataset so that only upland areas would be considered. Tree density was calculated using the point-centered quarter method described by Cottam and Curtis (1956). The point-centered quarter method is based on the distance between the plot center, and the nearest tree in up to four quadrants. If the distance to the nearest tree is large, then tree density is low; if the distance is short, then tree density is high. All witness trees for each LTA were tabulated by species and 5.1 cm (2 in.) diameter class. The percentage of each species by size class was calculated and multiplied by the number of trees per hectare in each LTA to create estimates of trees/ha. Any species that represented less than 1% of the total number of witness trees was placed in the 'other' category. The resulting stand tables thus represent average conditions of upland forests in each LTA at pre-settlement times.

To describe current forest conditions for comparison with pre-settlement forest conditions, we summarized data from the USDA Forest Service's 1996 Forest Inventory and Analysis (FIA) data for each LTA. FIA is a vegetation inventory focusing on timber attributes that employs permanent, fixed-radius plots that are periodically resampled (USDAFS, 2002). We used FIAMODEL (Pugh et al., 2002) together with ArcView GIS 3.2 (ESRI Inc., 1999) to summarize FIA data and construct forest stand tables for each LTA. FIA points were excluded if stands were less than 40 years of age, so that data from recently cut or young stands would not be mixed with data from more mature stands. FIA points were also excluded if they had been partially harvested in the last 10 years. Lowland forest types were also excluded.

2.3. Sensitivity analysis

The Public Land Survey records are not without their limitations. First, relatively small numbers of trees sampled per point requires the use of a large number of data points across a large area in order to include sufficient numbers of witness trees for analysis. Thus, it is difficult to capture small-scale variations in density, clustering, or species composition.

In order to explore the range of variability that may have occurred on the landscape, we created subsets of the Public Land Survey data. For the Perkinstown Moraines LTA and the Siren Plains LTA, the data points were divided into two categories: the bottom quartile of all sections in terms of tree densities and the top quartile. Stand tables were created for each of these categories. Also, since the pine barrens areas have been described as having ''scattered stands of trees'' (Curtis, 1959), we considered a clumped dispersion of trees for the Danbury-Trego Plains, and compared it to a random dispersion for that LTA while keeping tree density constant at 10.3 trees/ha.

The second limitation of the Public Land Survey data is that they do not include representative numbers of small diameter trees. There are two possible reasons for this; first, the 1846 and 1851 instructions required that witness and bearing trees be ''alive and healthy and not less than 5 in. diameter'' (Bourdo, 1956); second, smaller trees may have had too little area on which to inscribe all of the pertinent information (Bourdo, 1956). The Public Land Survey records also do not contain data on understory vegetation or coarse woody debris. There is some description of the understory in the Public Land Survey records, such as 'nettles' or 'thicket', but there is no detailed information about understory composition. Larger areas of standing dead wood caused by natural disturbance are noted in the Public Land Survey data, but within a stand or other area, generally no record is made of coarse woody debris, snags, stumps, or other dead wood.

In order to evaluate the visual impact of the lack of representation in the smallest diameter classes, we created an additional stand table for the Newood Moraines LTA. The Public Land Survey data for both LTAs within the Perkinstown End Moraine subsection followed a trend of increasing number of trees per hectare with decreasing diameter beginning with the largest diameter classes down to the 25.4 cm class. This is an expected distribution for an uneven-aged second or old growth forest. Size classes below 25.4 cm tail off rapidly, due to their under-representation in the Public Land Survey data. However in a northern hardwood-hemlock forest, significant numbers of small size class trees should be represented (Goodburn and Lorimer, 1999). We replaced the density values for the 5.1–20.3 cm DBH classes with estimates obtained by fitting a diameter distribution with a q-factor of 1.35. In other words, the density of the largest diameter class is multiplied by 1.35 to obtain the density of the next smallest class and so on (Fig. 2). This type of negative exponential relationship is often used as a guide for managing uneven-aged stands, and is applied here to supply hypothetical density numbers for the smallest size classes.

In both pre-settlement and current forest visualizations, we randomly placed small numbers of grasses, forbs, and shrubs to represent 'minimum' ground cover conditions. This was done to avoid an artificial looking bare ground appearance. It is likely that ground cover differed between pre-settlement and current forests, but no data is available on this aspect of forest structure. This is why we decided to use identical ground cover rather than visualizing speculative changes in ground cover (Wilson and McGaughey, 2000).

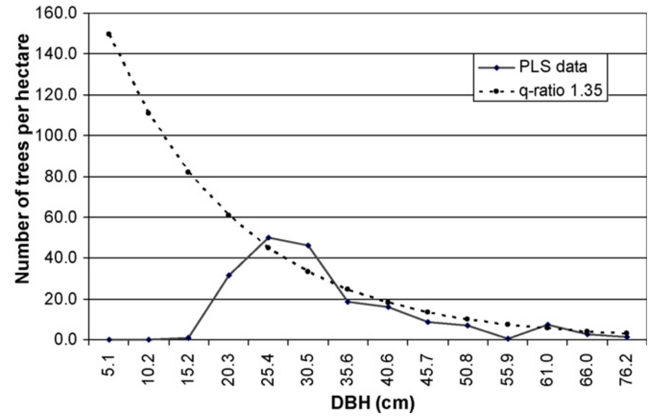

Fig. 2. Diameter distribution curve for the Newood Moraines LTA with raw data, and a q-factor of 1.35.

2.4. Visualization

To create imagery depicting historic and current forest conditions, we decided to use computer visualization software. Other approaches to visualize forest conditions, such as artist drawings, are certainly no less powerful in their visual depictions, however, computer visualizations were easier for us to generate, and are easier to reproduce. Data from the stand tables were entered into World Construction Set version 6.0 (WCS) (3D Nature, LLC 2002). Using methods described in Stoltman et al. (2004), images were created representing both the pre-settlement and current conditions for the four LTAs. To create these images, photos of individual trees were obtained for all tree species and size classes found in Wisconsin. Additional tree images created using Tree Professional version 5.0 (Onyx Computing 2000), a software package designed to create digital tree imagery, were used to fill in gaps where 'real' tree photos were not available. These images comprised 6% of the tree images used in the visualizations.

For each visualization, a randomly generated digital elevation model was employed. The 'camera' within WCS was set 2 m above ground level, with a 62.3° field of view, approximately 45 m from the forest edge. This results in an image of an area approximately 53 m wide by 31 m tall (e.g., Fig. 3a–g). The exception to this method was the visualization of the clumped distribution of the Danbury-Trego Plains, where the camera was set at 120 m above the ground looking down at an angle of 35°.

3. Results

3.1. Pre-settlement forests

The Public Land Survey data provided us with a representative record of forest composition and structure prior to European settlement. In the following, we introduce first the

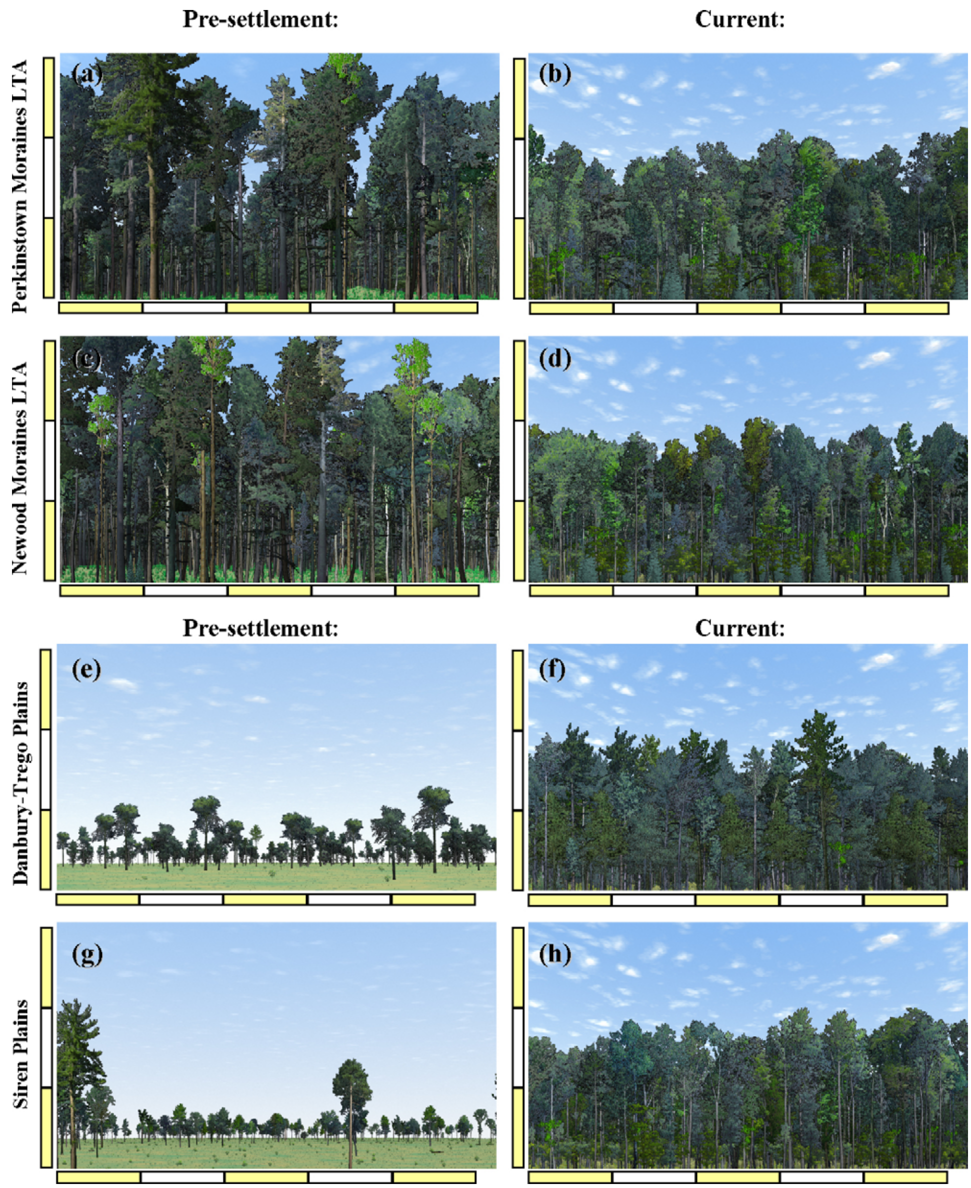

Fig. 3. Visualizations of the pre-settlement and the current forests in two land type associations each in the Perkinstown End Moraine (a–d) and the Bayfield Sand Plains (e–h) subsections. Point of view is 2 m above ground level, with a 62.3° field of view, approximately 45 m from the forest edge. Each yellow or white scale bar is 10 m.

results for mean forest conditions in each forest type. However, it is important to note that there is considerable variation in the witness tree data, and visualizations of the bottom and top quartile of the density distribution are described below. The Perkinstown Moraines LTA contained a total of 1638 witness trees with a tree density of 184.1 trees/ha (Fig. 3a). While this density may appear low, it has to be kept in mind, that the witness tree data contains only trees with a dbh of 20 cm or larger. Eastern hemlock dominated this area, comprising 57.3% of trees, with yellow birch being the next most abundant at 13.9%. Stems equal to or greater than 76.2 cm (30 in or larger) in diameter made up 5.9% of the witness trees (Fig. 4a). For the Newood Moraines, a total of 760 witness trees were processed, yielding a tree density of 191.1 trees/ha, a condition slightly more dense than the Perkinstown Moraines (Fig. 3c). The most dominant species here was also eastern hemlock, but to a lesser degree (47.4%). Yellow birch was the next most abundant species (23.3%), more abundant than in the Perkinstown Moraines LTA. Stems that are 76.2 cm (30 in.) in diameter only made up 0.66% of the witness trees, and no trees were larger than 76.2 cm (Fig. 4a).

In contrast to the hemlock-hardwood stands on rich soils, the Bayfield Sand Plains subsection exhibited much lower tree densities and pine-dominated forest types (Fig. 3e and g). The Danbury-Trego Plains yielded a total of 506 witness trees, with a density of 10.3 trees/ha. This area was heavily dominated by jack pine comprising 81.6% of the witness trees. Red pine was the next most common tree species with 15.6% of the witness trees. Trees $\geq$ 50.8 cm (20 in.) in diameter made up only 3.4% of the witness trees (Fig. 4b). For the Siren Plains, 979 witness trees were processed, yielding a calculated density of 9.7 trees/ha, similar to the Danbury-Trego Plains. Eastern white pine was

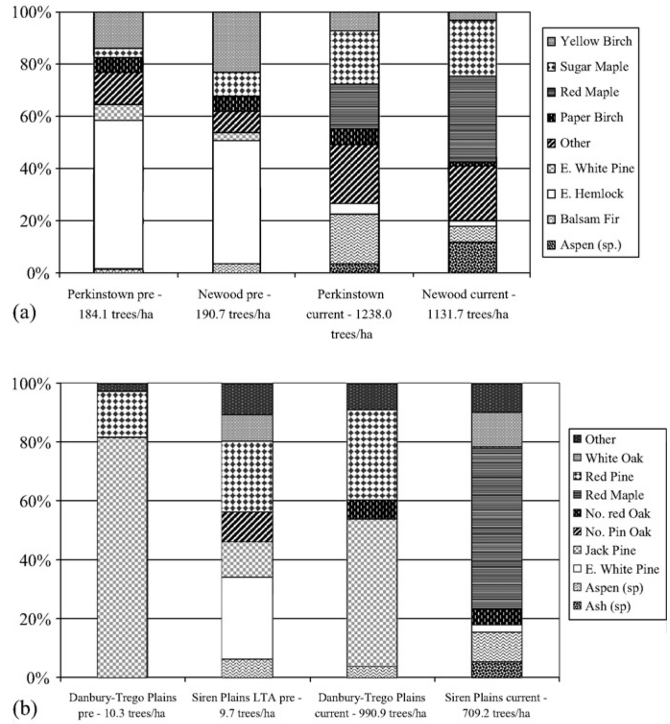

Fig. 4. Species compositions of the pre-settlement and the current forests in (a) the Perkinstown End Moraine subsection and (b) the Bayfield Sand Plains subsection.

the most common witness tree, comprising 27.9% of the sample, followed by red pine, at 24.1% of the witness trees. Trees $\geq$ 50.8 cm in diameter made up 20.0% of the witness trees (Fig. 4b).

3.2. Pre-settlement versus current forests

Stand composition and structure at pre-settlement times differed substantially from current conditions (Fig. 3a–h). Current stands were denser, contain smaller trees, and had a different species composition. In the Perkinstown Moraines LTA, current FIA data shows a tree density of 1238 trees/ha in all size classes and all species. Sugar maple was the most abundant species representing 20.6% of the trees, followed by balsam fir (*Abies balsamea*) at 19.2% of the trees. Eastern hemlock was only 4.0% of the trees. The largest trees were only 40.6 cm (16 in.), a DBH size class representing only 0.6% of the trees. Black cherry (*Prunus serotina*) represented 3.6% of the current forest, while it was not noted in the Public Land Survey records. Conversely, eastern white pine and northern white cedar (*Thuja occidentalis*) were noted in the Public Land Survey records, but were not represented in the FIA data. In the Newood Moraines LTA, the current estimated tree density is 1132 trees/ha. Red maple (*Acer rubrum*) was the most common species representing 32.8% of the trees, followed by sugar maple at 21.4%. The largest trees occurred in the 40.6 cm size class but represented only 0.2% of the trees. Eastern hemlock was reduced to only 2.0% of the trees from 47.4% as calculated from the Public Land Survey records. Red pine and red maple are currently found in the Newood Moraines LTA, but were not noted in the Public Land Survey notes. Eastern white pine was not represented in the FIA data, but it was present in the pre-settlement data.

In the Danbury-Trego Plains, tree density increased from 10.3 trees/ha in pre-settlement times, up to 991 trees/ha today. Jack pine was still the most abundant species representing 50.1% of the trees, followed by red pine at 30.7%. The largest trees were in the 40.6 cm size class, representing 0.2% of the trees. Northern red oak, paper birch (*Betula papyrifera*), and quaking aspen (*Populus tremuloides*) occurred in the FIA data but were not noted in the Public Land Survey data. In the Siren Plains LTA, density increased from about 10 trees/ha up to 709 trees/ha currently. Red maple was the most abundant species with 54.7% of the trees, mostly in the 5.1 cm (2 in.) size class. White oak (*Quercus alba*) was the next most abundant species representing 11.8% of the trees. Eastern white pine had declined to only 2.4% of the trees from 27.9% as calculated from the Public Land Survey records. Red maple, ash species (*Fraxinus* sp.), and northern red oak were present currently, while jack pine was no longer found.

3.3. Sensitivity analysis

Within a given LTA, there was substantial variation in terms of pre-settlement stand densities (Fig. 5a–d). For the Perkinstown Moraines LTA, the 1.6 km $\times$ 1.6 km (1 mi $\times$ 1 mi) sections representing the bottom quartile of tree densities yielded 675 witness trees, with a tree density of 108.1 trees/ha. Eastern hemlock comprised 57.2% of the witness trees and yellow birch comprised 15.3% (Fig. 5a). The sections representing the highest 25% of tree densities yielded 708 witness trees and a tree density of 379.3 trees/ha. Eastern hemlock is still the most common species with a slightly higher density of 61.7% of witness trees, followed by yellow birch at 12.4% (Fig. 5b). The differences in the forest structure between the bottom and the top quartile are clearly reflected in the visualizations of both (Fig. 5a and b), highlighting the variability of pre-settlement forest conditions across the landscape.

For the Siren Plains LTA, the sections representing the bottom quartile of tree densities yielded 383 witness trees, with a tree density of 4.8 trees/ha. Eastern white pine comprised 31.9% of the witness trees and red pine comprised 19.8% of the witness trees (Fig. 5c). The sections representing the highest 25% of tree densities yielded 400 witness trees with a tree density of 33.3 trees/ha. Red pine is the most common species with a slightly higher density of 28.3% of witness trees, followed by eastern white pine at 27.0% (Fig. 5d). Again, the visualizations of the top and the bottom quartile show that differences in density have a strong effect on the visual appearance of the forests.

For the Danbury-Trego Plains, one possible scenario of a clumped distribution has been visualized for comparison with a random distribution (Fig. 5g–h). In this example, there are 2.5 clumps/ha with an average of 4 trees/clump. Although tree density remains the same as with the visualization with

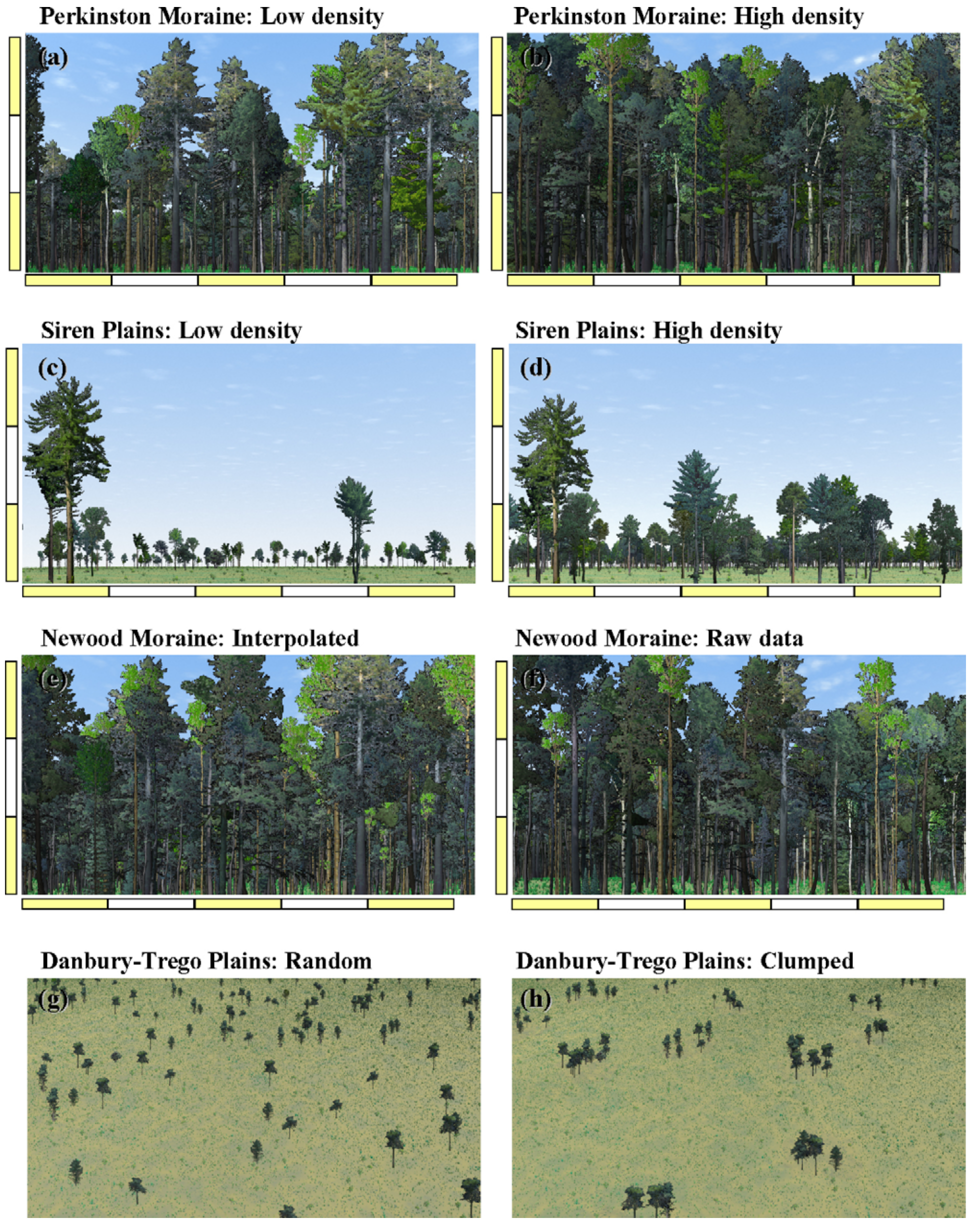

Fig. 5. Visualizations of the Perkinstown Moraines LTA (a and b) and the Siren Plains LTA (c and d) using sections with the lowest 25% of tree density, and the highest 25% of tree density; visualization of the Newood Moraines LTA with interpolated numbers for the smallest size classes (e) and from raw data (f); visualizations of the Danbury-Trego Plains LTA from 120 m elevation with random tree spacing (g) and in small clumps (h).

randomly placed trees, the overall impression of that area is that tree density is lower.

By extrapolating numbers for the smallest size classes for the Newood Moraines, the density increased from 190.7 to 567.9 trees/ha (Fig. 2). When comparing pre-settlement visualization with and without trees in the smallest size classes the difference in forest structure is evident (Fig. 5e and f). As would be expected, the addition of trees in the smaller size classes creates the impression of a much denser forest (Fig. 5e). However, the major differences from pre-settlement conditions to current conditions remain. Even when we add trees in the small size classes based on the extrapolation, the current forest is about twice as dense as in pre-settlement times, and there is a broader range of size classes in the pre-settlement forest.

4. Discussion

This study is the first to create realistic images of Wisconsin's pre-settlement forests based on quantitative data. We visualized and compared pre-settlement forest conditions with current forest conditions and contrasted average conditions. We explored some of the variability that existed by examining different density classes within those datasets.

In our first study area, the Perkinstown End Moraine subsection, forests with relatively low tree densities (<200 trees/ha in pre-settlement times), have been replaced by stands with densities of over 1000 trees/ha. Pre-settlement forests were more structurally diverse, containing more size classes of trees. There is also a significant change in species composition, eastern hemlock and yellow birch which were dominant at pre-settlement times, are largely replaced by red and sugar maple.

In the Bayfield Sand Plains, the pre-settlement visualizations show barrens communities with very low tree densities (approximately 10 trees/ha) dominated by large pines. Visualizations of current forest conditions show closed forests with tree densities that are nearly 100-fold higher than in pre-settlement times. In the Danbury-Trego Plains LTA, the proportion of pines is still very high, but in the Siren Plains, species composition shifted to more hardwood species, and jack pine is no longer represented.

The use of computer visualizations carries the ethical responsibility of portraying historical and current landscapes so that they reflect the available data most closely (Sheppard, 1989; Wilson and McGaughey, 2000). Not only is it important to base visualizations on the best available data, but it is also necessary to include factors that occur on the landscape such as roads, slash, stumps, and the effects of natural disturbances when applicable (McQuillan, 1988). For this study, there were some limitations in data that prevented us from adhering completely to this ideal. Examples of this include the lack of data on snags and coarse woody debris, as well as limited information about small diameter trees and forest understory. For this reason, we visualized the raw data available to us, and then in certain cases, i.e., filling in small size classes using the q-factor, we created new visualizations based on the assumption that the data available was incomplete. In general, the inclusion of any such assumption into the creation of imagery must be approached on a case-by-case basis, and be clearly reported.

We also suggest that it is important to visualize not only the average forest conditions, but to provide visual examples of the variability in a given area. This variability has two potential sources. The first is true differences among forests on the ground. The second source of variability is that samples do not capture conditions perfectly, and will add further variability to a given dataset. In our sensitivity analysis, we visualize both low- and high-density forests within the same ecoregion to highlight the variability inherent in our samples. The fact remains though, that all visualizations of the pre-settlement conditions, no matter which part of the density distribution they are based on (Figs. 3a and 5a and b), are strikingly different than current forest conditions (Fig. 3b).

In summary, we have created a method to visualize pre-settlement forests using Public Land Survey data. With these visualizations we obtain a picture of the average conditions that existed across an LTA, not just a snapshot of any given forest stand. Computer visualization of pre-settlement forest conditions is an obvious extension of emerging technologies that help satisfy public interest in issues related to forest management. Visualization offers the opportunity to quickly convey information that previously has only been available in tabular format. For education and extension use, computer visualization can increase our understanding of the impacts, both positive and negative, that humans have on the landscape. It can be a powerful tool not only as a visual reference point for restoration and management, but also as an aid in understanding the variability of conditions in the past, current, and future landscapes.

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