Buckthorn in the Oak Openings

Final Report

Lake Erie Protection Fund Project SG#416-11

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Abstract:

In the Oak Openings the invasive shrubs common and glossy buckthorn (*Frangula alnus* and *Rhamnus cathartica*) directly threaten native biodiversity and habitat health of this globally rare ecosystem. A time series of 49 Landsat TM and ETM+ satellite images from 2001 to 2011 was used define the land surface phenology of buckthorn thicket and map its extent and change both at Irwin Prairie State Nature Preserve, and throughout Oak Openings. Buckthorn thicket was identified in 0.43 % of the classified pixels (940 ha) in the 2007–2011 imagery and in 0.31 % (690 ha) of the 2001–2006 images. The areal extent of buckthorn thicket increased by 39 % (255 ha) in the study area over the time period from 2001 to 2011. Results of these are available as an interactive web map at:

http://www.eesescience.utoledo.edu/Faculty/Becker/Data/Invasives.html

Factors contributing to these increases, including nutrient loading and groundwater flow patterns at IPSNP were measured. These results preliminarily indicate that under certain circumstances there is nutrient contribution due to inundation from agricultural ditches which affects surface water cover, which in turn can affect buckthorn distribution.
Executive Summary

Locations of dense buckthorn thickets in the Oak Openings Region were identified from satellite data, and factors affecting the location of these dense invasive buckthorn thickets were investigated. Landsat TM and ETM+ satellite images from 2001 to 2011 were used to map the extent and change of the invasive shrubs common and glossy buckthorn (*Frangula alnus* and *Rhamnus cathartica*) at Irwin Prairie State Nature Preserve (IPSNP), and throughout Oak Openings, a 1,500 km$^2$ region, located in NW Ohio, USA and SE Michigan near Lake Erie. In the Oak Openings, buckthorn directly threatens native biodiversity and habitat health of this globally rare ecosystem. Buckthorn that forms as dense shrub thicket in the understory is often obscured from satellite view by other canopy and is not spectrally dissimilar enough to be characterized using multispectral images. To address this, time series tasseled cap greenness images of land surface areas dominated by buckthorn was used to identify areas covered by thicket with a heterogeneous background. A time series of vegetation index values was calculated from 49 Landsat images and combined with in-situ observations to define the land surface phenology of buckthorn thicket and other vegetation types. Buckthorn thicket was identified in 0.43 % of the classified pixels (940 ha) in the 2007–2011 imagery and in 0.31 % (690 ha) of the 2001–2006 images. A Kappa test of the 2007–2011 classification yielded a value of 0.73 with 88 % overall accuracy of presence or absence of thicket based on 60 samples throughout the Oak Openings. The areal extent of buckthorn thicket increased by 39 % (255 ha) in the study area over the time period from 2001 to 2011. Results of these are available as an interactive web map at: http://www.ees.science.utoledo.edu/Faculty/Becker/Data/Invasives.html

Factors contributing to these increases, including nutrient loading and groundwater flow patterns at IPSNP were measured. These results preliminarily indicate that there is nutrient contribution due to inundation from agricultural ditches which affects surface water cover, and buckthorn distribution, but this recharge pulse is not strongly seen in the groundwater flow patterns.
Introduction

The main purpose of this study was to use satellite images from 1984-2010 to map the extent and density of invasive shrub thicket (dominantly common and glossy buckthorn) at Irwin Prairie State Nature Preserve (IPSNP), and throughout the entire Oak Openings region. This mapped distribution can then be used to identify specific hydrologic and nutrient characteristics of areas prone to these dense thickets, which are detrimental to the health of a unique Lake Erie basin habitat. We generated field verified maps of areas with extensive invasive thicket, and generated a model of factors affecting their occurrence. These products will be useful for land managers throughout the region to both identify problem areas, and effectively document buckthorn management through time in the Oak Openings region. Complementing this, we conducted surface and ground water sampling, and installed 9 piezometers to monitor groundwater elevations in the near surface. These groundwater levels were used to establish flow directions and investigate any changes in groundwater flow due to surface water ponding and recharge.

Study Area

The Oak openings, located in NW Ohio and extending into SE Michigan is a globally rare ecosystem contained entirely in the Lake Erie watershed (figure 1). This region provides the home to rare organisms which depend on the extent of the ecosystem. For example, the purplish copper is an endangered species of butterfly that depends on water smartweed that grows in IPSNP, and only grows in wet prairies. In the Oak openings, invasive plant species are a direct threat to biodiversity and habitat health by outcompeting native plants by and forming dense monocultures. At IPSNP buckthorn has emerged as a great threat to the Great Lakes twig rush prairies. Other invasives which form similar thickets in the region include honeysuckle and autumn olive. All of these are listed by the Ohio DNR in their top 10 invasive plants. The native plant communities are adapted to low nutrients and periodic fires conditions and invasions are
successful when this regime is disrupted either through suppression of fires or an influx of nutrients.

Figure 1: Study Location

Methods

Mapping of buckthorn in the region is necessary in order to better understand the environmental factors that influence the distribution of the buckthorn, and to improve and document habitat management. Remote sensing can be used as a tool to map these invasive plants through time. To do this, we used a time series sequence of >65 Landsat images, as well as *in-situ* observations of buckthorn’s characteristic phenologic cycle (buckthorn leafs out earlier, and holds its leaves later), to define the phenology of buckthorn in the region. We use this to map the extent of buckthorn using a supervised classification
method. We then verify presence of buckthorn and measured canopy coverage with field surveys in areas ranging from free of buckthorn to high density thicket to measure accuracy. These field measures of vegetation density together with the satellite image sequences were used to develop a measure of vegetation health and extent of invasive thicket throughout the Oak Openings. Validation of this method indicates accuracy of >90% of correct identification of presence or absence of thicket based on 50 random samples throughout the Oak openings (see example interpreted image on attached map).

**Determination of Buckthorn Phenology in Region**

The phenology of buckthorn species is different from other vegetation species in the study area. Buckthorn leafs out earlier and remains green longer than a majority of the tree canopy (shown in Figure 2). The NDVI and tasseled cap greenness of other land covers either remains fairly constant throughout the year (pine plantation, water, urban), starts later and ends earlier (oak savanna, oak blueberry forest), or does is not as high (wet prairie, grasslands). Agricultural fields exhibit land surface phenologies related to time of planting and crop type. As a result, pixels dominated by buckthorn species exhibit a distinct land surface phenology which can be used to discriminate these pixels from those with other land covers utilizing only a time series of vegetation indices throughout the course of a year.

To generate the Landsat based land surface phenology, and classify areas for presence/absence of buckthorn thicket, the following steps were conducted:

Forty-nine images were acquired from the USGS Eros Data Center. Images from Landsat 5 TM and Landsat 7 ETM+ were acquired covering path 20 and row 31 (Table 1). Scenes were selected to minimize cloud cover over the area. To eliminate inter-annual variation due to drought, data was not selected for the image stacks during years in which the monthly historical Palmer Drought Severity Index (PDSI) for the study area showed moderate to severe drought conditions (PDSI below -2.0) for more than two consecutive spring and summer months (Palmer 1965).
Images were atmospherically corrected using the FLAASH atmospheric correction package implemented in the ENVI software (Cooley, Anderson et al. 2002). Visibility at the Toledo Express airport was obtained for the hour closest to scene acquisition for model input (Roche 2011). Toledo Express is located at the center of the scene of interest. Orbital parameters, scene center acquisition date/time, latitude and longitude of scene center were acquired from the image headers.

Images were co-registered and resampled to a common base image. In order to allow for the highest quality vegetation index generation, nearest neighbor resampling was used to preserve the original spectra.

The co-registered, atmospherically corrected land surface reflectances were used to calculate Tassel-Cap Greenness (TC-G) transformation (Crist and Kauth 1986) using the formula:

\[ G = -0.2728TM1 - 0.2174TM2 - 0.5508TM3 + 0.7221TM4 + 0.0733TM5 - 0.1648TM7 \]

Enhanced Vegetation Index (EVI) and Normalized Difference Vegetation Index (NDVI) were also calculated for the same scenes based on the same co-registered atmospherically corrected images.

Locations with known-type land surface coverage were identified in the field, including buckthorn thicket, turf grass, evergreen forest, open water, asphalt, oak forest, wet prairie, and oak savanna. An area of interest, with a minimum of 15 pixels and a maximum of 300 pixels, was defined for each of these land cover types. TC-G, EVI and NDVI images spanning 2007-2011 were stacked in an image stack indexed by day of year, generating a land-surface phenology curve for each pixel location throughout the entire region. For each of the land cover types, a time series of each vegetation index was extracted using the z-profile tool in ENVI based on the area of interest chosen for each of the designated type land surface coverages (figure 2).
Buckthorn Mapping

An image stack for 2007-2011 was generated for each vegetation index, indexed by day of year within the image stack. The parallelepiped method of image classification was employed on each time series stack and locations with buckthorn thicket were identified using training sets that were obtained from field sites that were identified as buckthorn thicket. In addition, the maximum likelihood classification method was used, using phenology of buckthorn thicket, turf grass, evergreen forest, open water, asphalt, oak forest, wet prairie, and oak savanna, as the land cover classification types. The accuracy assessment used for each image classification based on field validation data was also assessed and is discussed below.
Image stacks covering the periods 2001-2006, and 2007-2011 were generated. Based on the accuracy assessment results, the TC-G was selected as the best vegetation index, and the parallelepiped classification method as producing the most accurate results as determined by the kappa test. The land surface phenology curves were resampled to the day of year indices that were used in each image stack. The TC-G image stacks were classified using the resampled phenology curves with the parallelepiped classification method. (Figure 3)

**Figure 3**: Buckthorn thicket location derived from Landsat TM and ETM data

The TC-G image stacks were classified using the resampled phenology curves with the parallelepiped classification method. (Figure 3)
Field Characterization of Vegetation

To provide a basis for validation of the remotely sensed classification of buckthorn species thicket, the following field measurements were conducted at IPSNP and Bumpus Pond, a property owned by Toledo Area Metroparks. Both of these properties have extensive buckthorn thickets and are actively managed to remove buckthorn and restore native wet prairie.

Areas of buckthorn thicket were sampled for stem density, species composition, and canopy closure to determine the definition and variability of thickets at a set of ten P-Plot locations (Figure 4). Nested vegetation sampling has been widely used as a means to provide an accurate representation of both plant species richness and diversity at multiple spatial scales from 1 m$^2$ to 1000m$^2$ plot sizes (Stohlgren, Falkner et al. 1995). Pixel nested plot (P-Plot) sampling utilizes a similar sampling style as a modified-Whittaker plot but at a scale that is similar to the nominal ground resolution of sensors such as Landsat TM and ETM+” (Kalkhan, Stafford et al. 2007). Due to the impenetrable nature of buckthorn thickets, a 30x30m P-Plot (a hybrid of a pixel nested plot and a modified Whittaker plot) was used. Figure 3 shows the layout of the plot. Because graminoids and non-woody herbaceous species in this study area make a minimal contribution to overall reflectance values at the 30m Landsat scale, their presence was noted in each sub-plot, but only woody plants were considered during sampling. Ten 1mx1m plots and two 3mx3m (A and B) were sampled for stem density, species composition, and canopy closure. All species within the 10mx10 m sub-plot (C) were noted for presence. The larger 30m x30m plot was surveyed for species that were not found in any of the smaller plots.
A spherical densitometer was used to determine canopy coverage (Lemmon 1956). Each subplot was averaged to determine species composition, density, and canopy coverage for the entire 30mx30m plot. Based on these ten P-plot locations, distributed over a 6.5 km\(^2\) area in a variety of buckthorn densities, a characterization of low, medium, and high buckthorn coverage was determined and used for a rapid assessment of larger numbers of locations.

In addition, 50 sample locations throughout the Oak Openings in a 35 km\(^2\) area were selected for method validation. Based on the measurement of buckthorn density at the ten P-plot locations, a measure of “low”, “medium” and “high” was assigned to samples at 50 other selected sample locations (Table 2).

**Accuracy Assessment**

The image classification results and field measurements were compared to determine the accuracy of products derived using the above method. The classifications of buckthorn derived from each of the
vegetation (TC-G, EVI, NDVI) index stacks using each classification method on the 2007-2011 image stacks were checked against the results of field measurements. Measurements at the ten P-plot sites and the 50 other field validation sites were used to assess the accuracy. Kappa values were calculated for each image interpretation method (Congalton 1991) for the presence or absence of buckthorn thicket at locations throughout the images.

**Topographic Controls**

To identify environmental factors affecting thicket location, examined relationships with topography, aspect, surface hydrologic pathways, subsurface geology and surface and groundwater nutrient content. Surface drainage was modeled from LIDAR data using the TOPAZ method in a GIS environment. During melt events, water was seen to flow from the ditch to the IPSNP, delivering nutrient rich sediment laden water and returned to the ditch having deposited the sediment. We mapped the areas subject to inundation at IPSNP due to flooding in the closest agricultural ditches (Figure 5). Based on the LIDAR DEM, corrected for culvert locations, we were able to map the extent of flooding due to increased water head in the local agricultural ditch. This rich flow from the ditch remained as surface ponding resulting in local recharge in the western grasslands area. This surface ponding is seen to coincide with the mapped buckthorn thickets in the study area.

**Groundwater Flow:**

Ground water flow was found to be generally from SE to NW (Figure 6a,b). The most significant variations were seasonal changes in ground water table elevation from spring to fall, as illustrated in Figure 6. Flow direction and gradient was consistent throughout the year. There was no significant change in gradient or direction associated with inundation events in surface water. Localized changes in recharge due to surface water ponding were not evident in gradient changes. To investigate magnitude of any recharge from flooding events, further geochemical sampling would be necessary.
Surface Flow Event:

**Figure 5:** Surface flow event from March 2011, illustrating surface delivery of nutrient rich sediment from agricultural ditch overflow event
Figure 6: Groundwater flow from May and Aug 2012
These results are made available through as a google earth kmz file, so that users may examine them in detail. Google earth kmz files were chosen as the web GIS distribution method, as they allow users to view and integrate the results both into GIS viewers, but also into the more commonly used Google Earth and Google maps platforms. This file is available at:

http://www.eesescience.utoledo.edu/Faculty/Becker/Data/Invasives.html
Schedule:
Activities associated with this project:

Summer 2011:

Field Measurement of buckthorn thicket; Groundwater level monitoring; Surface water sampling; Image processing algorithm refinement based on field data

Fall 2011:

Field validation of senescence timing at Irwin Prairie; image processing and validation; Groundwater level monitoring; Surface water sampling

Winter 2011:

Groundwater level monitoring; Completion of image processing; Development of conceptual model of environmental factors from physical parameters

Spring 2012:

Groundwater level monitoring; Surface water sampling; Final field verification and completion of maps; Distribution of maps; Preparation of manuscript
**Project Deliverables:**

As a result of this project we developed the following products:

- A Field validated map of current locations of buckthorn thicket in Irwin Prairie, and throughout the Oak Openings Region.

- A standard methodology to generate maps of buckthorn for future years.

- Buckthorn thicket location maps for two time periods in the Oak Openings between 1984-2011.

- A conceptual model of environmental factors contributing to the formation of thick buckthorn thickets.

- A web based GIS interface of these maps to enable distribution to the entire community of stakeholders.

Maps and models generated by this project have been shared with stakeholders in the community. These include groups who manage land in close proximity to Irwin Prairie, and have expressed interest in these products, specifically Toledo Metroparks (Secor, Oak Openings and Wildwood Metroparks) and the Nature Conservancy (Kitty Todd), as well as the Ohio DNR (Divisions of Forestry and Natural Resources: Lou Campbell State Nature Preserve and Maumee State Forest) (see map). We have made these maps available through a web based GIS. We will also distribute an animation of the change in buckthorn/invasive population since the early 1980s, to show both how buckthorn has impacted the region, and how management efforts are addressing problem areas.
Products:

The following Publication was produced based on this grant work:


The following presentations were made based on this grant work:


Zmijewski, K.*, Becker, R.H. UT, 2012, A bird’s eye view: tracking the progress of the invasive species Glossy Buckthorn (Rhamnus alnus) using Landsat imagery, ASPRS Annual Conference, Pasadena, CA

Web GIS

A Web GIS Interactive map which shows the results of this work is available at:

http://www.eescience.utoledo.edu/Faculty/Becker/Data/Invasives.html

A kmz file which contains the results, and can be downloaded for local use is contained on that page.

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References Cited:


