Abstract

Defoliation by the northern tamarisk beetle (Diorhabda carinulata) causes changes in the reflectance of tamarisk (Tamarix spp.) canopies. Cross coregional spectral matching was used to examine spectral separability of green, yellow desiccated, brown desiccated, and dead tamarisk canopy types. Using a feature selection technique (the instability index), four spectral regions were identified as important for canopy type discrimination, including one red (645-693 nm), one near infrared (735-946 nm), and two shortwave infrared regions (1,960-2,090 nm and 2,400-2,478 nm). The random forests decision tree algorithm was used to compare classification performances of full-range and feature-selected hyperspectral spectra as well as simulated WorldView-2 spectra. Classification results indicated that the process of feature selection can reduce data redundancy and computation time while improving accuracy of tamarisk canopy type classification.

Introduction

Tamarisk (Tamarix spp., a.k.a. saltcedar) is one of the most widely dispersed invasive plant species in the western United States, occupying an estimated 526,000 hectares and causing ecosystem service-related economic losses ranging between 133 and 285 million US dollars annually (Zavaleta, 2000), not to mention millions of dollars spent on eradication and restoration projects (Hultine et al., 2010a). Previous studies have reported that tamarisk has cumulative negative effects on riparian ecosystems, such as reduced biodiversity, increased soil surface salinity, changes in riparian wildfire occurrence, and water use (Dudley et al., 2006; Shafroth et al., 2005). In order to control tamarisk, the northern tamarisk beetle (Diorhabda carinulata) has been released in the western United States (Tracy and Robbins, 2009). The beetle removes the leaf cuticle of tamarisk and eats the leaf mesophyll cells selectively in both the larval and adult stages, leading the leaf to desiccate and drop (Plate 1) (Meng et al., 2012; Nagler et al., 2014). Defoliation may not kill the tamarisk plant, and in many cases, tamarisk can refoliate in six to eight weeks after defoliation; however, studies show that the repeat defoliation caused by the tamarisk beetle can increase tamarisk mortality (Carruthers et al., 2008; Dudley and Bean, 2012; Nagler et al., 2014). Repeat herbivory caused up to 40 percent tamarisk defoliation; however, studies show that the repeat defoliation have used multispectral remote sensing data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper+ (ETM+) and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments. Dennison et al. (2009) mapped defoliation of large, dense tamarisk stands on the Colorado and Dolores Rivers using both ASTER and MODIS imagery. ASTER normalized difference vegetation index (NDVI) and MODIS enhanced vegetation index (EVI) both declined during periods of defoliation. Using Landsat TM imagery, Meng et al. (2012) compared two algorithms for has spread to an extensive area that is unrealistic to track and analyze from the ground (Nagler et al., 2014). Projected climate warming and drying trends in the southwestern United States may increase the over-winter survival of beetle populations, and consequently lead to increased herbivory (Dale et al., 2001; Raffa et al., 2008). Remote sensing techniques may be the most effective way to evaluate the effectiveness of tamarisk bio-control at the landscape scale (Dennison et al., 2009; Meng et al., 2012; Nagler et al., 2012; Snyder et al., 2012; Nagler et al., 2014). Nevertheless, previous remote monitoring studies of tamarisk defoliation have not differentiated between desiccated (live) tamarisk canopies and dead tamarisk canopies at the stand scale (Dennison et al., 2009; Meng et al., 2012; Nagler et al., 2012; Nagler et al., 2014). Desiccated and dead tamarisk canopies will have very different ecosystem impacts, since desiccated canopies will regrow leaves and resume photosynthesis and transpiration. Identifying the spectral differences between green, desiccated and dead tamarisk canopies may help establish more informative and accurate assessment of tamarisk bio-control impacts and assist development of more adaptive management plans.

We hypothesized that spectral analysis techniques developed for hyperspectral processing can be used to study spectral features of tamarisk canopies and spectral separability among green, desiccated and dead tamarisk canopy spectra. If accurate classification of tamarisk canopy types based on field spectroscopy is proven feasible, hyperspectral and/or high spatial resolution imagery may be useful for mapping tamarisk bio-control impacts. The objectives of this study are to: (a) develop a methodology for selecting suitable wavelengths for discrimination of green, desiccated and dead tamarisk canopies, and (b) analyze the spectral signatures of these canopy types at both fine and coarse spectral resolutions.

Background

Previous studies of tamarisk defoliation by the northern tamarisk beetle have used multispectral remote sensing data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper+ (ETM+) and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments. Dennison et al. (2009) mapped defoliation of large, dense tamarisk stands on the Colorado and Dolores Rivers using both ASTER and MODIS imagery. ASTER normalized difference vegetation index (NDVI) and MODIS enhanced vegetation index (EVI) both declined during periods of defoliation. Using Landsat TM imagery, Meng et al. (2012) compared two algorithms for...
detecting tamarisk defoliation, the forest disturbance index (Healey et al., 2005) and a decision-tree model (random forests) (Breiman, 2001). Nagler et al. (2012) developed an approach for estimating regional evapotranspiration (ET) and foliage density changes caused by beetles using Landsat TM and MODIS data. Their results for six western US rivers indicated that defoliation events contributed to about 15 percent of the overall ET and foliage density reduction, with defoliation events contributing to about 15 percent of the overall ET and foliage density reduction, with marked variations among river systems. Snyder et al. (2012) compared ET and carbon flux measured by eddy covariance to NDVI calculated from Landsat TM and ETM+ data. Declines in NDVI occurred during summer decreases in leaf area and ET caused by defoliation (Snyder et al., 2012). Nagler et al. (2014) synthesized MODIS data, networked digital camera images and ground surveys to track beetle dispersal and its impacts on the Virgin River from 2010 to 2013. They concluded that beetle damage progressed at a rate of about 25 km yr⁻¹, much faster than previous expectations, and caused a 50 percent reduction in leaf area index and ET of tamarisk stands by 2012.

Identification of desiccated or dead tamarisk canopies may be aided by the availability of high spatial resolution (e.g., GeoEye, WorldView) or hyperspectral (e.g., Hyperion, AVIRIS) remote sensing data. High spatial resolution images may reduce spectral mixing at the stand scale to allow the separation of desiccated and dead canopies (Dennison et al. 2009, Meng et al. 2012), and can estimate ET at plant canopy scales (Nouri, 2014). In contrast with multispectral data, spectroscopic (hyperspectral) analysis can resolve spectral features related to vegetation structure and biochemistry using hundreds of near-contiguous narrow bandwidth channels (Ustin et al., 2004). As a result, hyperspectral data have been used to assess spectral separability among different vegetation species (Dennison and Roberts, 2003; Pu, 2009; Van Aardt and Wynne, 2001), to estimate the change in biochemical compounds caused by disturbance or stress (Bian et al., 2010; Estep and Carter, 2005; Pu et al., 2008), and to distinguish between green plant, plant litter, and soil at both leaf and canopy levels (Nagler et al., 2000; Nagler et al., 2003; Inoue et al., 2008). After measuring spectral reflectance of plant litter and soil samples using a spectroradiometer, Nagler et al. (2000 and 2003) found no unique spectral feature for discrimination of plant litter and soil existing in the visible or near infrared (NIR) spectral regions. However, in the shortwave infrared (SWIR) region, an absorption feature associated with cellulose and lignin was found and a corresponding spectral index called cellulose absorption feature (CAI) was designed to quantify plant litter cover (Nagler et al., 2000; Nagler et al., 2003).

Various non-photosynthetic vegetation and green vegetation cover types have been successfully classified through spectral matching and linear mixture modeling techniques (Cochrane, 1998; Roberts et al., 1998; Datt, 2000; Hostert et al., 2003; Herold et al., 2004; Daigo et al., 2004; Zhang et al., 2006; Sonnentag et al., 2007; Zhang et al., 2007; Pacheco and McNairn, 2010; Haest et al., 2013; Somers and Asner, 2013). Spectral matching is one of the most widely used spectroscopic techniques, aiming to detect targeted pixels or endmembers, while linear spectral mixture analysis (LSMA) is designed for disaggregating mixed spectral pixels from remote sensing data. Asner and Lobell (2000) claimed that a careful selection of wavelengths or spectral features for LSMA may improve classification accuracy and reduce computation complexity. Somers et al. (2010) developed and tested an automated LSMA algorithm, known as stable zone unmixing (SZU), to overcome the limitations of the AutoSWIR algorithm presented by Asner and Lobell (2000). The stability index (IST) was calculated to select stable spectral features (Somers et al., 2008). IST accounted for both the spectral variability within a class and the spectral similarity among classes to indicate the most useful and stable wavelength ranges over the full spectral range. Somers and Asner (2013) demonstrated that a proper wavelength selection strategy could avoid redundant information and improve classification accuracies, by emphasizing the subtle spectral and phenological differences among targeted classes. Discrimination of defoliated and dead tamarisk canopy types could benefit from a similar wavelength selection strategy.

**Material and Methods**

**Study Site and Spectral Measurement**

The study site was located at the University of Utah Rio Mesa Center, 65 km northeast of Moab in southeastern Utah. The riparian corridors along the Dolores River at Rio Mesa Center consist of dense tamarisk stands as well as some native cottonwood (Populus fremontii) and willow (Salix gooddingii) trees. As a first step towards spectroscopic analysis, the reflectance of green, desiccated and dead tamarisk canopies was measured in situ along the Dolores River over the 350-2,500 nm wavelength range using an Analytical Spectral Devices (ASD) field spectrometer with a 25° field of view (PANalytical; Analytic Spectral Devices, Boulder, Colorado). A white spectranon standard was used to calibrate the spectral measurements. The full-width-at-half maximum (FWHM) and the sampling interval of the spectrometer for the 350-1,050 nm spectral range were 3 nm and 1.4 nm, respectively. Over the 1,050-2,500 nm spectral range, the FWHM and sampling interval were 8 nm and 2 nm. A Gaussian function with a 5 nm FWHM was used to resample the 1 nm instrument output. The reflectance measurements were carried out in early October 2013 within two hours before or after solar noon to reduce solar zenith angle effects, and under cloudless sky conditions. Reflectance spectra were measured from nadir at a height of approximately 15 cm above the canopy using a pistol grip with extension. The representative tamarisk canopy types (green, desiccated and dead) with different heights along riparian corridors were selected in situ to ensure significant variations in ground cover fractions and reflectance spectra. Desiccated tamarisk canopies showed two colors: yellow and brown (Plate 1). Dead canopies were devoid of desiccated leaf material, with only branches showing (Plate 1). Reflectance measurements for selected targets were performed five times and averaged for analysis. In total, 67 canopy spectra were collected and analyzed including 17 green, 15 dead, 27 yellow desiccated, and 8 brown desiccated canopies. Means and standard deviations for reflectance spectra of green, brown desiccated, yellow desiccated and dead canopies are shown in Figure 1. The major absorption regions influenced by atmospheric water vapor content were excluded from analysis (Somers et al., 2009).

**Cross Correlogram Spectral Matching**

A suitable number of mapping classes is important for improving classification accuracy and efficiency (Richards and Jia, 2006). Desiccated tamarisk canopies showed two distinct colors (yellow and brown) in situ (Plate 1) representing different desiccated status, while Figure 1 indicated the spectral signatures of yellow and brown canopies were similar. Considering the computational task of remote sensing classification, it may be beneficial to examine if spectral separability between yellow and brown desiccated canopies is minor or if it is reasonable to split the desiccated canopy type into two subtypes (yellow and brown). A spectral matching technique called cross correlogram spectral matching (CCSM) was implemented to compare the spectral separability of different tamarisk canopy types (Van Der Meer and Bakker, 1997). CCSM compares the differences between a reference spectrum and an unknown spectrum in the form of reference amplitude as
Figure 1. (a) Reflectance spectra of green, (b) brown desiccated, (c) yellow desiccated, and (d) dead tamarisk canopies. Atmospheric absorption regions were excluded.

Plate 1. Photographs of (a) green, (b) brown desiccated, (c) yellow desiccated, and (d) dead tamarisk canopies in situ.

Figure 1. (a) Reflectance spectra of green, (b) brown desiccated, (c), yellow desiccated, and (d) dead tamarisk canopies. Atmospheric absorption regions were excluded.
well as shape variations. In the CCSM procedure, a reference spectrum is compared to a “test” spectrum by calculating the linear correlation coefficient between the two spectra at different match positions (Van Der Meer and Bakker, 1997; Datt, 2000). The cross correlogram function can be created by plotting the correlation coefficients against match positions. The location of the correlation maximum also indicates the degree of similarity between the test spectrum and the reference spectrum. The cross correlogram shape for high similarity is parabolic and symmetric around match position 0 with a peak correlation near to 1; on the contrary, the cross correlogram shape for low similarity is skewed with the correlation peak shifted towards either positive or negative match positions (Datt, 2000). Cross correlograms were calculated and inspected visually for different canopy type combinations (Figure 2), where “canopy type combination” refers to the comparison between a test spectrum (i.e., an averaged spectrum of samples from one tamarisk canopy type) and a reference spectrum (i.e., an averaged spectrum of samples from a second tamarisk canopy type) when applying CCSM.

The Instability Index

ISI was used to identify wavelengths that were least sensitive to spectral variability for tamarisk canopy classification (Somers et al., 2008). ISI was calculated as the ratio of the within-class variability to the between-class variability (Somers et al., 2010):

\[ ISI = \frac{m}{m(m-1)} \sum_{i=1}^{m} \sum_{j=1}^{m} \frac{1.96(\delta_2 + \delta_3)}{|R_{i,j} - R_{i,j}|} \]  

(1)

where \( R_{i,j} \) and \( R_{i,j} \) are the reflectance values at wavelength \( i \) for class \( z \) and class \( j \), respectively, and \( \delta_2 \) and \( \delta_3 \) are the standard deviations at the same wavelengths of class \( z \) and \( j \), respectively, and \( m \) is the number of classes. An ISI value that is below one indicates the between-class variability exceeds the within-class variability, while an ISI value which is above one signifies the opposite trend. Wavelengths with an ISI value below one are expected to contain useful information for spectral feature separation and should be selected for further analysis (Somers et al., 2010).

Low ISI values were found for four spectral regions within the canopy spectra. Two of these spectral regions (red and NIR) corresponded to spectral regions covered by the high spatial resolution WorldView-2 multispectral instrument. WorldView-2 provides one panchromatic band (0.5 m spatial resolution) and eight multispectral bands (2 m spatial resolution) with an average revisit time of 1.1 days (Table 1; http://digitalglobe.com). Considering the size and distribution of tamarisk stands along riparian corridors, WorldView-2 is one of the most suitable sensors for high spatial resolution remote monitoring of tamarisk defoliation and mortality, but lacks SWIR bands found on coarser spatial resolution sensors. Field-measured spectra were convolved using a sensor response function in ENVI software (http://www.exelisvis.com/) to simulate WorldView-2 multispectral spectra. ISI was also applied to select bands from the simulated WorldView-2 spectra. Following this convolution step, four sets of spectra were used for random forests classification analysis: full-range field spectra, feature-selected field spectra, simulated WorldView-2 spectra with all eight bands, and feature-selected WorldView-2 spectra with only bands 5 through 8 (Table 1).

<table>
<thead>
<tr>
<th>Band1 (coastal)</th>
<th>400-450</th>
<th>Band5 (red)</th>
<th>630-690</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band2 (blue)</td>
<td>450-510</td>
<td>Band6 (red edge)</td>
<td>705-745</td>
</tr>
<tr>
<td>Band3 (green)</td>
<td>510-580</td>
<td>Band7 (NIR1)</td>
<td>770-895</td>
</tr>
<tr>
<td>Band4 (yellow)</td>
<td>585-625</td>
<td>Band8 (NIR2)</td>
<td>860-1,040</td>
</tr>
</tbody>
</table>

Random Forests

The random forests (RF) algorithm was used to classify the tamarisk canopy field spectra and simulated WorldView-2 spectra. RF is a machine learning algorithm based on traditional decision tree classification. It randomly selects input variables from a large number of available variables and generates a large ensemble of independent tree classifiers that vote for class membership (Breiman, 2001). RF provides an internal unbiased estimate of the training set error called the out-of-bag (OOB) error (Breiman, 2001). During the process of RF classification, each tree classifier was constructed from bootstrapped samples comprising about two-thirds of the original dataset. Samples not used in the tree construction were put in the tree classifier to get a classification. In the end, a class is given to the largest number of votes from the OOB sample. The ratio of the times that a class is not the true class across all bootstrap iterations is called the OOB error estimation (Breiman, 2001). In addition, standard methods for evaluating classification accuracies such as confusion matrices and the kappa coefficient (Congalton, 1991a and 1991b; Congalton

Figure 2. Cross correlograms using each tamarisk canopy type: (a) green, (b) brown desiccated, (c) yellow desiccated, and (d) dead as the reference over the 350-2,500 nm region.
and Green, 2009) were calculated to compare the RF classification of green, desiccated, and dead tamarisk canopies using full-range field spectra, feature-selected field spectra, 8-band simulated WorldView-2 spectra, and bands 5 through 8 from simulated WorldView-2 spectra.

### Results

#### CCSM Results

Green, desiccated, and dead tamarisk canopy spectra had important differences in their reflectance spectra, but yellow desiccated and brown desiccated spectra were similar in terms of amplitude and shape (Figure 1). Mean green and desiccated canopy spectra possessed a steep increase in reflectance beyond visible wavelengths (>700 nm, referred to as the "red edge"), while the mean dead canopy spectrum showed a continual, gradual increase in reflectance. The contrast between the red and NIR spectral regions was highest for the mean green canopy spectrum, similar for both mean desiccated canopy spectra, and lowest for the mean dead canopy spectrum. The region with the highest reflectance (750-1,300 nm), called the "near infrared plateau," contains a unique plant spectral feature. Two liquid water absorption features were evident on the NIR plateau (centered near 980 and 1,200 nm for both green and desiccated canopy spectra. The NIR plateau is produced by high internal lignin and cellulose absorption in the SWIR between 2,000 and 3,000 nm, while this spectral feature is not readily apparent in green or desiccated canopy spectra (Figure 1), due to the changes in foliar water content (Gates et al., 1979, Rock et al., 1988).

The SWIR spectral region has been identified as sensitive to vegetation moisture and senescence, and thus may be suitable for discrimination of green, desiccated and dead vegetation (Nagler et al., 2000; Nagler et al., 2003; Inoue et al., 2008; Piekarczyk et al., 2012). In the SWIR region, differences in amplitude can be observed among all the tamarisk canopy types (Figure 1), due to the changes in foliar water content (Gates et al., 1965): the mean dead canopy spectrum had the highest reflectance value, the mean green canopy spectrum had the lowest, and the mean desiccated canopy spectra (brown and yellow) were in the middle but similar. The mean and ±1 standard deviation dead canopy spectra show evidence of lignin and cellulose absorption in the SWIR between 2,000 and 2,200 nm, while this spectral feature is not readily apparent in green or desiccated canopy spectra (Figure 1).

CCSM results were consistent with the visual assessment of reflectance spectra (Figure 2): in comparison to other canopy type combinations, spectra of yellow and brown desiccated canopies were very similar with little difference, and the dead canopy spectrum was significantly different from the spectra of other canopy types. The cross correlogram with the reference spectrum itself was parabolic and nearly symmetrical with a correlation maximum up to 1 at match position 0, indicating a perfect match. Canopy type combinations using the green, yellow desiccated, and brown desiccated canopy spectra as reference spectra showed that the dead canopy spectrum was distinct. The dead canopy cross correlograms were highly skewed with much smaller correlation coefficients, and the correlation peak was shifted towards positive match positions (Figure 2). The cross correlograms for yellow/brown desiccated canopy
and green canopy combinations were moderately skewed, but the correlation maxima were still high around match position 0; most important of all, the cross correlograms of yellow and brown desiccated canopy combinations were mostly indistinguishable. Since the differences between yellow and brown desiccated canopies were proven to be small and hard to distinguish, these canopy types were combined into a single desiccated canopy type for further analysis.

**Feature-selected Wavelengths**

Figure 3 plots ISI values based on the reflectance of green, desiccated and dead canopy spectra as a function of wavelength. As previously explained in the Instability Index Section, low ISI values were expected to correspond with low levels of similarity between canopy types and/or low levels of variability within each canopy type indicating high separability. In the end, the feature-selected wavelengths with low ISI values were found in four spectral regions: one red region (645-693 nm), one NIR region (735-946 nm), and two SWIR regions (1,960-2,090 nm and 2,400-2,478 nm). In previous studies, these regions were sensitive to changes in chlorophyll, damaged leaf layer structures and loss of water content (Knipling, 1970; Heller, 1978; Boochs et al., 1990; Carter, 1993; Radeloff et al., 1999; Lentile et al., 2006; Inoue et al., 2008; Piekarczyk et al., 2012).

![Image](204_March_2015_PHOTOGRAMMETRIC_ENGINEERING_REMOTE_SENSING)
RF). The step of feature selection might be useful not only for spectral mixture analysis of hyperspectral remote sensing, but also for multi-spectral remote sensing classifications. The red, NIR, and SWIR wavelength regions were found to be important for discriminating desiccated and dead canopy spectra. Our analysis shows again that the variations in spectral signatures caused by stress or disturbance are not equal across the full wavelength range, and that spectral features at specific wavelengths are valuable for monitoring disturbed or stressed plant canopies (Ahern et al., 1991; Radelfo et al., 1999; Hurley et al., 2004; Santos et al., 2010).

Further studies evaluating the impacts of the tamarisk biocontrol program could be accomplished using data acquired from high spatial resolution sensors (i.e., WorldView-2) and ground-based ET measurements. More detailed and accurate mapping of tamarisk canopy classes may be possible with high spatial resolution, multispectral data. By exploring the relationship between spectral indices and ground-based ET measurements, high spatial resolution data may also assist in assessing water salvage (Nouri, 2014). Multi-temporal analysis using either high spatial resolution multispectral or hyperspectral data may also result in improved classification of tamarisk defoliation and mortality, as well as identification of mortality trends over time.

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References


Table 4. RF Confusion Matrices for Dead, Green, Yellow, and Brown Canopies Using Feature-Selected Canopy Spectra

<table>
<thead>
<tr>
<th></th>
<th>Dead canopies</th>
<th>Brown canopies</th>
<th>Green canopies</th>
<th>Yellow canopies</th>
<th>User’s accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dead canopies</td>
<td>14</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>93.3</td>
</tr>
<tr>
<td>Brown canopies</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>0.0</td>
</tr>
<tr>
<td>Green canopies</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>4</td>
<td>76.5</td>
</tr>
<tr>
<td>Yellow canopies</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>18</td>
<td>66.7</td>
</tr>
<tr>
<td>Producer’s accuracy (%)</td>
<td>87.5</td>
<td>0.0</td>
<td>81.3</td>
<td>58.0</td>
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<td>OOB error (%), Kappa and run time (seconds)</td>
<td>32.84</td>
<td>0.526</td>
<td>0.74</td>
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Table 5. RF Confusion Matrices for Dead, Green, Yellow, and Brown Canopies Using Simulated Feature-Selected WorldView-2 Spectra

<table>
<thead>
<tr>
<th></th>
<th>Dead canopies</th>
<th>Brown canopies</th>
<th>Green canopies</th>
<th>Yellow canopies</th>
<th>User’s accuracy (%)</th>
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<tr>
<td>Dead canopies</td>
<td>12</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>80.0</td>
</tr>
<tr>
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<td>0</td>
<td>1</td>
<td>0</td>
<td>7</td>
<td>12.5</td>
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<tr>
<td>Green canopies</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>3</td>
<td>82.4</td>
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<tr>
<td>Yellow canopies</td>
<td>2</td>
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<td>2</td>
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<tr>
<td>Producer’s accuracy (%)</td>
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<td>33.3</td>
<td>87.5</td>
<td>61.8</td>
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<tr>
<td>OOB error (%), Kappa and run time (seconds)</td>
<td>28.36</td>
<td>0.585</td>
<td>0.07</td>
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Tracy, J.L., and T.O. Robbins, 2009. Taxonomic Revision and Biogeography of the Tamarix-Feeding Diorhabda elongata (Brulle, 1832) Species Group (Coleoptera: Chrysomelidae: Galerucinae: Galerucini) and Analysis of Their Potential in Biological Control of Tamarisk, Magnolia Press, Auckland, New Zealand, 152 p.


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