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Caso práctico

Monitoring macrophytes cover and taxa in Utah Lake by using 2009-2011 Landsat digital imagery

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Abstract

Macrophytes serve a valuable function in lake ecosystems; they stabilize sediments and associated nutrients, and they provide important habitat for fish and wildlife. As such, the coverage and taxa composition of macrophytes have been selected as priority parameters for monitoring the Utah Lake ecosystem. The goal of this project was to develop a macrophyte monitoring procedure for Utah Lake' tributary watershed using Landsat imagery to map macrophyte vegetation distribution around the lake. We first used a combination of GPS points collected in the field and points extracted from a high resolution image to train a macrophyte distribution model. Some 500 GPS points were divided into four categories: 1. Open water, 2. Phragmites australis, 3. Typha latifolia (Bullrush) and 4. Terrestrial vegetation. We then established the spectral signatures and statistically isolated the four categories. Finally, we employed a hybrid classification, a combination of supervised (SEE-5 software) and unsupervised classifications to isolate the pixels representing the four classes. After several attempts a preliminary model showed a 74% and 78% mapping accuracy for Phragmites australis, and Typha latifolia (Bullrush) respectively. It also showed an overall mapping accuracy of 67% for the four classes. There is an ongoing process to improve model's accuracy with more field data. Once our macrophyte model is calibrated, we plan to map historical macrophyte distribution and taxa composition using a 1984-2012-time series of Landsat images. The proposed procedure has proven invaluable to Utah Lake ecosystem monitoring efforts.

Key words: Macrophytes, Landsat TM, SIG, remote sensing, Lake, spectral classification, Utah.

Resumen

Monitoreo de la cobertura de la vegetación macrófita en el Lago Utah usando imágenes satelitales Landsat de 2009-2011

Los macrófitos cumplen una función valiosa en los ecosistemas lacustres, estabilizan los sedimentos y nutrientes asociados, y proveen un hábitat importante para los peces y la vida silvestre. Por lo tanto, la composición de los taxones y la cobertura de macrófitos han sido seleccionados como prioritarios para el seguimiento de los parámetros del ecosistema del Lago Utah. El objetivo de este proyecto era iniciar un procedimiento de control de macrófitos en la cuenca afluente del Lago Utah, usando imágenes Landsat para cartografiar la distribución de la vegetación de macrófitos alrededor del lago. En primer lugar, utilizamos una combinación de puntos GPS recolectados en el campo y puntos extraídos de una imagen aérea de alta resolución

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para entrenar un modelo de macrófitos. Unos 500 puntos GPS se dividieron en cuatro categorías: 1. Aguas abiertas, 2. Phragmites australis, 3. Typha latifolia (Bullrush) y 4. Vegetación terrestre. A continuación, se establecieron las firmas espectrales, aisladas estadísticamente de las cuatro categorías. Finalmente, se empleó una clasificación híbrida, una combinación de supervisada (software SEE-5) y clasificaciones no supervisadas para aislar los píxeles que representan las cuatro clases. Después de varios intentos un modelo preliminar mostró una precisión de clasificación del 74% y 78% para Phragmites australis y Typha latifolia (Bullrush) respectivamente. También se mostró una precisión de clasificación general del 67% para las cuatro clases. Actualmente se está en proceso de mejora de la exactitud del modelo con más datos de campo. Una vez que nuestro modelo de macrófitos esté calibrado, tenemos la intención de cartografiar la distribución histórica y composición de macrófitos utilizando una serie temporal de imágenes Landsat de 1984-2012. El procedimiento propuesto en este estudio ha demostrado ser muy valioso para los esfuerzos de monitoreo del ecosistema del LagoUtah.

Palabras clave: Macrófitos, Landsat TM, SIG, Teledetección, Lagos, Clasificación espectral, Utah.

Introduction

Macrophyte abundance has multiple functions in a Lake. It stabilizes sediments, retains nutrients, and provides habitat for fish and wildlife and help to accelerate positive changes in water quality. It is a key ecosystem component, and has been selected as one of the priority performance measures for reporting yearly ecosystem status. Without aquatic plants, near-shore wave activity is not suppressed and sediments typically anchored by their roots become suspended in the water column and add to already increased turbidity of the lake. The extent of macrophytes in Utah Lake varies directly with water clarity and near-sediment light levels, and inversely with water depth. Because macrophytes responds to water clarity, which is affected in part by the amount of nutrients / algae present in the water, it also is an important performance measure for evaluating the success of nutrient reduction efforts in the Utah Lake.

The incorporation of remote sensed and spatial related data is something that can produce excellent results in measuring macrophytes cover increase/decrease over time. GIS and remote sensed data manipulation provide the advantage of working in a multivariate scenario capable of managing multiple axes of variables ranges. Geospatial data are useful to provide understanding of the biological responses of fish species and their interactions with their surrounding environment, especially macrophytes cover and extent. This effort intends to estimate coverage and taxa composition of macrophytes in Utah Lake by extracting all the available spatial related data from a time series of Landsat images from 1984 to 2011 at a resolution of 30 by 30 meters.

We propose the annual assessment of existing and changing area coverage and taxa composition of macrophytes using Landsat digital imagery. We used to characterize the current abundance and species composition, and to determine if macrophytes are increasing in abundance with management actions. In essence, we investigated the capability of Landsat digital imagery for the spectral separation of macrophyte vegetation sampled within the Utah Lake in central Utah.

The primary goal of this project was to estimate coverage and taxa composition of macrophytes in Utah Lake and develop a monitoring protocol to estimate the total abundance and extension of macrophyte vegetation in Utah Lake using a spatially explicit method over time.

The research questions that we expected to answer with this research initiative were the following:

1. How much is the total abundance of macrophytes in Utah Lake?
2. What was the composition of the plant community of macrophytes in Utah Lake?
3. How we could develop a protocol to monitor the changes of macrophytes' distribution in Utah Lake?

The end product of this research was to provide a monitoring protocol using existing Landsat imagery series for tracking the extent and cover of macrophytes along the Utah Lake. We also intended to characterize macrophyte plant community by species, using spectral signals. This information can be then used to monitor changes of management actions that potentially affect submerged vegetation —macrophytes— extent and other related resources along the Utah Lake.

Methods

Study Area

Utah Lake is the largest freshwater to the west of the Mississippi. It is located within 40°14'42"N and 111°47'51"W coordinates (Figure 1). Its catchment area is of 9,960 km^2. It is a remnant of a much larger pleistocene lake called Lake Bonneville, which existed from 75,000 to 8,000 years ago. At its peak 30,000 years ago, Lake Bonneville reached an elevation of 1,550 m above sea level and had a surface area of 51,000 km^2, which was nearly as large as Lake Michigan (SWCA, 2007). Utah Lake is within Utah Valley, in north-central Utah. Mountains surround Utah Valley on three sides: The Wasatch Range to the east, Traverse Mountains to the north, and Lake Mountain to the west. Mount Nebo reaches an altitude of 3,616 m, and Mount Timpanogos reaches an altitude of 3,580 m, nearly 2,210 m above the valley floor.

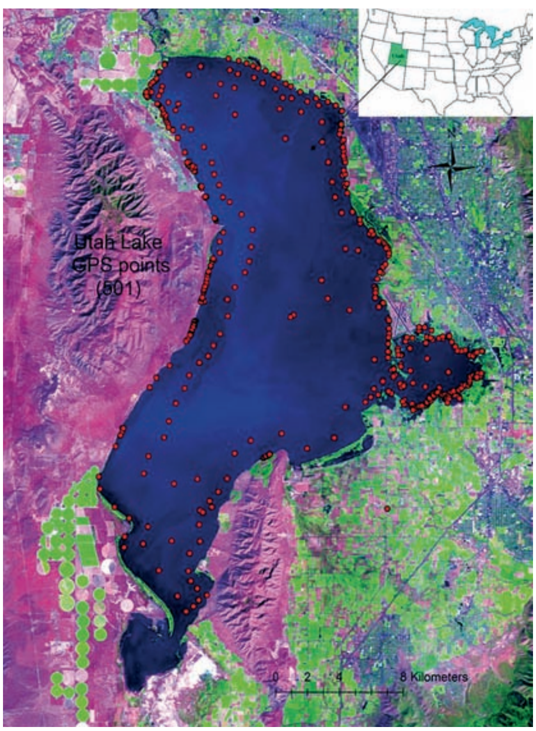

Figure 1. GPS-sampling of macrophyte vegetation locations growing around the Utah Lake. Some 500 GPS points were located *on screen* sampling on high resolution image and in the field (ground truth data). Upper map shows location of Utah Lake.

On the western side of Utah Valley, the Utah lake is overlooked by Mount Timpanogos and Mount Nebo. Primary inflows Provo and Spanish Fork Rivers and primary outflows Jordan River. The lake's only river outlet, the Jordan River, is a tributary of the Great Salt Lake and is highly regulated with pumps. Evaporation accounts for 42% of the outflow of the lake, which leaves the lake slightly saline (SWCA, 2007). The elevation of the lake is legally at 1,368 m above sea level. If the lake elevation goes any higher, the Jordan River pumps and gates are left open.

Taxa Composition

The Common reed, *Phragmites australis*, is a large perennial grass and it is found in wetlands of temperate and tropical regions of the world and 3-4 species are recognized. It is largely known as an invasive species and produces harmful toxins for other plants. In the US, there is a large debate if it is native or exotic specie. It tolerates some salinity and spread as a floating mat in 1-m dept waters (Wu, 1990).

Typha latifolia is a flowering plant in the family Typhaceae. There are around eleven species distributed mainly in the Northern Hemisphere. It is also known as bulrush, bullrush, reedmace, cattail, catninetail, punks, or corndog grass (Wu, 1990). It is also considered as invasive and grows in turbid waters.

Geo-Spatial Data Compilation

As part of this geo-spatial data base development process, a time series of Landsat

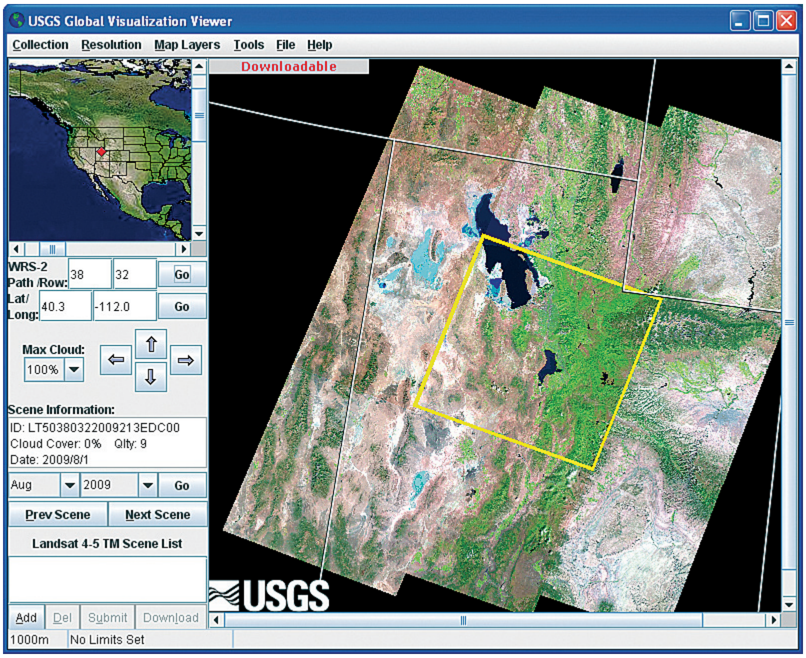

Figure 2. Picture showing a Aug-2009 Landsat image from Utah Lake and surrounding areas. All images from 1984-2011 for this area were downloaded from this USGS glovis site (http://glovis.usgs.gov/). A later image of September-2011 was also downloaded to study macrophyte coverage changes.

images, from Utah Lake and surrounding areas were downloaded and organized. All images from 1984-2012 for this area were downloaded from the USGS glovis site (http://glovis.usgs.gov/). These images are now available for free at the USGS glovis web site and were selected, downloaded, pre-processed and stored in our geo-database. Figure 2 shows an Aug-2009 Landsat image as it is seen at the glovis web site. The selected images were within the growing season from the above mentioned years: May through September. These images will be used to detect macrophytes cover changes in a 28-year span and can be used to related macrophyte' plant population decline or increase through these years.

We collected all shape files available at the AGRC —Official Utah state site— (http://agrc.utah.gov/). We also gathered all geographic information available at Crowl's aquatic Lab at Utah State University and the GIS files available at the Utah's Division of Wildlife Resources (UDWR) field office in Springville, Utah. The geo-data base is composed of all GIS layers in raster and vector format- of Utah Lake and the surrounding areas. Inconsistencies and duplicates of the information were also checked and updated as needed. The data and the format of the data were also checked and reviewed. Some of the historic or past data did not have accurate location records. UTM of all points of interest and sampling locations were manually added to most of the locations and data records.

Field Data Collection: Sampling

We started collecting field sampling data (GPS points) along with points extracted from 1-foot (0.3 meter) high resolution aerial color photos to train a model. A preliminary effort was done (Figure 1), by locating 42 macrophyte site locations. They were geo-referenced in July of 2010 and then in July 2011 some other 100 locations were identified and georeferenced. These GPS points were collected and divided in four categories: 1. Open water, 2. *Phragmites australis*, 3. *Typha latifolia* (Bullrush) and 4. Terrestrial vegetation. A fifth class of *Mixed vegetation* (Phragamatis and Bullrush) was used in the 2009 classification model. Each site was identified with a UTM coordinate using a

Figure 3. Image Pre-processing using ERDAS Imagine software: All seven bands (files, TIFF files) were downloaded and collapsed to form a single file (img format) using the "layer stack" function. Picture shows a Subset of the 2011-September Landsat image after it has been atmospherically corrected.

GPS unit. Field data were recorded onto paper field forms and subsequently entered into a database. Field forms were developed in an Access database to record GPS coordinates and photos of field sampling locations. A total of 500 field samples were collected from different field and digital sources. These data were used as a field-input data in these analyzes. Data layers were produced by clipping raw data layers to a 100 meters buffered the lake boundary, and then scaling by standard deviation. The standard deviations were multiplied by 100 and rounded to the nearest whole number.

Image Processing

Image pre-processing was performed using ERDAS Imagine Ver 9.4 software: All seven bands (files, TIFF files) were downloaded and collapsed to form a single file (img format) using the "layer stack" function (Figure 3). Most remote sensing derived data were obtained from Landsat TM scenes taken in 2009 and 2011.We used the software ERDAS Imagine to process the 2009 and 2011 maps. Once this procedure was fine tuned on the 2009- image, consecutives procedures were utilized to obtain the 2011 model. Spatial data was manipulated using ArcGIS ver 9.4.

An Image standardization procedure was performed in all images. This allows elimination of glare, haze, and corrects satellite angle distortion and other atmospheric abnormalities. Picture in Figure 4 shows a Subset of the 2011-September Landsat image after it has been atmospherically corrected. A procedure developed at Utah State University for correcting sun illumination geometry, atmospheric effects and instrument calibration (http://earth.gis.usu.edu/ imagestd/). It also converts Digital Numbers from raw data images into reflectance values. This procedure is necessary to establish homogenous conditions for all images for further comparisons.

Sampled brightness values for the macrophyte sites were tested for differences using

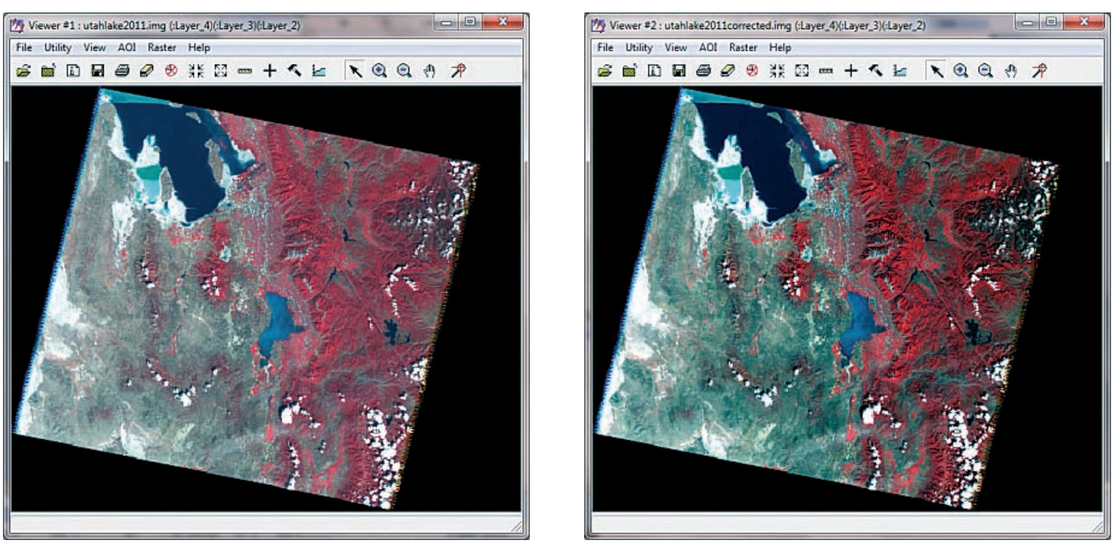

Figure 4. Image standardization procedure allows elimination of glare, haze, and corrects satellite angle distortion and other atmospheric abnormalities.

these spectral separation procedures (Werstak, 2004) 1) the Simple Ratio (near-infrared/red), 2) NDVI or Normalized Difference Vegetation Index (near-infrared – red/near-infrared + red), 3) near-infrared/green ratio, and 4) red/green ratio. Once we identified the best spectral separation procedure. We employed a hybrid classification (Jensen, 2005), a combination of supervised (See-5 software [RuleQuest Research, 2004] and NLCD —National Land Cover Dataset— extension) and an unsupervised classification —Cluster busting technique, which eliminates other clusters of pixels to isolate the pixels representing only the four studied classes vegetation—. This allowed us to establish the spectral signatures for the four sites types to statistically isolate the vegetation sites from the others.

Once we tested the estimation of macrophyte distribution with Landsat imagery and the procedures describe above, we conducted a discrimination procedure oriented to differentiate mainly *Phragmites australis* from *Typha latifolia*.

Data manipulation and analyzes were done mostly using the software Erdas Imagine version 9.1. All layers and data points were arranged in ArcGIS ver 9.4 GIS software. Data overlapping and sampling ("drilling"); the xy points into the layers, were used in Arc GIS using the sampling function in the spatial analysis tool box. The Raster calculator was used to draw the spatial distribution based on the resulting logistic model.

Classification Algorithm

Regression trees are used to predict a continuous dependent variable from one or more continuous and/or categorical independent variables. They offer certain advantages over other classification methods in that they are non-parametric and make no assumptions about the form (linear or non-linear) or the nature (monotonic or non-monotonic) of the relationship between predictor and dependent variables. They are also simple to interpret and easily implemented as a series of if-then statements applied to the independent variables to determine a set of end-nodes representing discrete, homogeneous distributions of the dependent variable (*Defries et al., 2000*). A clue to how they function is provided by their alternative name of recursive partitioning methods (Fielding, 1999).

Decision points are called nodes, and at each node the data are partitioned. Each of these partitions is then partitioned independently of all other partitions, hence the alternative name of recursive partitioning. This could carry on until each partition consisted on one case. This would be a tree with a lot of branches and as many terminal segments (leaves) as there are cases. Normally some 'stopping rule' is applied before arriving at this extreme condition. Inevitably this may mean that some partitions are 'impure' (cases are a mixture of classes), but it is necessary to balance accuracy against generality. A tree which produced a perfect classification of training data would probably perform poorly with new data (Eq. 1):

$$SS(t) = \frac{1}{N(t)} \sum_{i=1} n^i \left[f_i - f^-(t) \right]^2 \qquad [1]$$

Where $N(t)$ is the number of cases in node t, n_i is the value of the frequency variable, f_i is the value of the response variable (fraction i) and $f^-(t)$is the mean fraction for node t. Parent node splitting continues until one of the following specified criteria are met: a maximum number of 23 splits, a minimum of 5% reduction in error, or a minimum of five cases in each node. For all regression tree models, fractions were binned into 20% intervals, producing parent nodes that were sufficiently heterogeneous to allow node splitting based on the specified error reduction criterion. Individual fractions predicted separately were constrained to sum to one on a pixel basis.

Model Accuracy

In thematic mapping from geo-referenced data, the term accuracy is used typically to express the degree of 'correctness' of the predicting model (Foody 2002, Gilbert *et al*. 2005). Model accuracy assessment was performed in this study to compute the probability of error for the macrophyte

Table 1. Distribution of the four classes around the Utah Lake

Classes	Area (ha)	Area (%)
Open water	33,978.69	85.3
Phragmatis	3,947.76	9.9
Bullrush	992.43	2.5
Terrestrial vegetation	910.35	2.3
Total	39,829.23	100.0

prediction map (2009). Samples were “drilled” into the final prediction map to determine which samples fell correctly into the modeled classes (Lowry *et al*. 2008). Procedure involved the use of Arc GIS ver 9.2 and the spatial analysis tool: sampling. R statistical software was used for the calculations.

About 20% of the ground truth and on-screen sampling data enabled us to validate the map and measure the accuracy of the model using the overall accuracy of the model. The overall accuracy can be interpreted as follows: Values below 40% would suggest the agreement between reference data and the mapped data is poor and could occur by chance. Values between 40% and 80% represents moderate agreement and values over 80% represents strong agreement (Congalton and Green, 1999). A value of 70% or higher is expected and is acceptable for this study, since Landsat imagery is of moderate resolution.

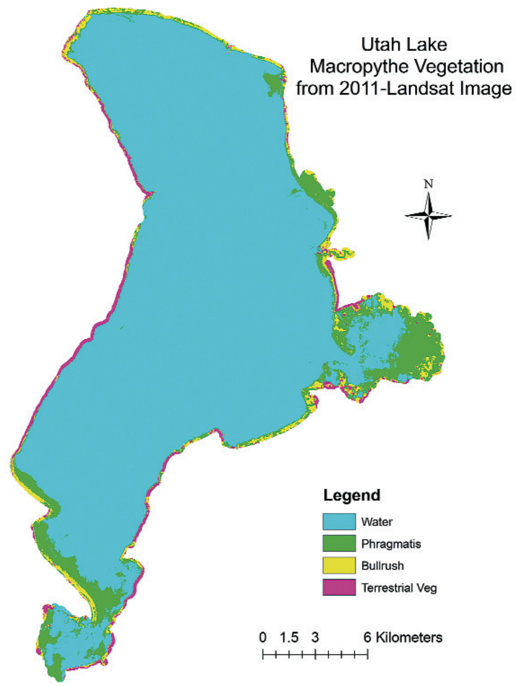

Figure 5. Final model of Macrophyte classification using a 2011-September Landsat image. Overall mapping accuracy was 67% and 74% for *Phragmites australis*, and 78% for *Typha latifoia* (Bullrush).

Results

Macrophyte Distribution

The four mapped classes showed a distribution in which around 33,000 has area occupied by open water, 3,947 has of Phragmatis (around 9.9%), 992 has of Bullrush (2.5%) and 910 has. of terrestrial vegetation growing around the lake (some 2.3%). (Table 1, Figure 5).

A logical distribution of macrophyte vegetation distribution was obtained and visualized in Figure 5. Phragmatis was mapped at the inner edge of the lake, close to the open water and Bullrush was mapped at the outer edge of the lake, which represents the actual, seen on the ground, distribution. Terrestrial vegetation was also mapped correctly, right at the shore line. Bullrush mapping areas showed a more realistic distribution (had the highest mapping accuracy) compared to the Phragmatis. Phragmatis showed a thicker layer around the lake shoreline that is observed in Figure 5. This thicker layer may be attributed to a confusing factor occasioned by the lake high turbidity and high algae production activity.

Model Validation

The overall accuracy for the 2009 distribution model was 61.27%; Bullrush grass had the highest mapping accuracy: 76% and Open water has the lowest mapping accuracy: 47%. This indicates that from all withheld sites 61.27% of the sites fell correctly into that class in the predicted model. The highest analyzed class; Bullrush had 76% accuracy (Table 2). In general, the model performed better at predicting the Phragamatis and Bullrush. The

Table 2. Confusion Matrix of the Five Classes Distribution Model around Utah Lake using a 2009-Landsat image

Classes	1 Water	2 Phragmatis	3 Bullrush	4 Mixed Vegetation	5 Terrestrial veg	Total
1 Water	88	6	2	11	2	109.00
2 Phragmatis	47	146	4	8	0	205.00
3 Bullrush	21	44	22	4	4	95.00
4 Mixed veg	25	22	1	25	0	73.00
5 Terrestrial veg	5	2	0	0	11	18.00
Total	186	220	29	48	17	500.00
Accuracy (%)	47	66	76	52	65	**61.27**

Table 3. Confusion Matrix of the Four Classes of Final Macrophyte Distribution Model around Utah Lake using a 2011-Landsat image.

Classes	1 Water	2 Phragmatis	3 Bullrush	4 Terrestrial veg	Total
1 Water	99	6	2	2	109.00
2 Phragmatis	54	147	4	0	205.00
3 Bullrush	25	45	21	4	95.00
4 Terrestrial veg	5	2	0	11	18.00
Total	183	200	27	17	427.00
Accuracy (%)	54	74	78	65	**67.52**

model also identified a clear and logical distribution pattern along the gradients of depth along the lake's shoreline Field visits around and within the lake were conducted.. A visual validation was performed using expert knowledge and field observations.

The 2009 prediction model served as a first step to work on a 2011- image. As you can see in Tables 2 and 3, the mapping accuracy improved in the 2011 model. The reason may be attributed to the elimination of the «mixed vegetation» class which was a confusing class. The spectral separation in the classification algorithm did not provide a clear discrimination among all other classes. Improvements in the 2011-classification can be seen in details in Table 3.

The overall accuracy for the 2011 distribution model was improved up to 67.52% (Table 3); Bullrush grass had the highest mapping accuracy: 78% followed by Phragmatis with 74%. Open water had the lowest mapping accuracy: 54% (Table 3). This indicates that from all withheld sites, 67.52% of the sites fell correctly into that class in the predicted model. In general, the model performed better at predicting the Phragmatis and Bullrush with the 2011-Landsat imagery. The model also identified a much better and logical distribution pattern along the gradients of depth along the lake's shoreline. A visual validation was also performed using expert knowledge and field observations. Final distribution was checked in the field and we agreed that final predicted distribution matches observed distribution.

Mixed vegetation was eliminated in the 2011-model and it seems to improve the model's accuracy. It was deducted that it was a confusing factor for the classification procedure. The general tendency of the model is the same, but the accuracy is slightly better in the 2011 when compared to the 2009 image classification's model.

We can also observe in the results that in both classifications, open water had always the lowest accuracy. That means that both models (2009 and 2011) overestimate macrophyte extension in the lake. Since clear water has a very distinct spectral signature, we believe that water turbidity and/or submerged macrophytes are affecting the classification. In fact, since this is a hypertrophic lake, the amount and concentration of algae, and in general: dissolved nutrients in the water column might had been affected the classification. We recommend the use of Normalized Difference Vegetation Index (NDVI) or other spectral separation indexes to define the range of open water values and isolate this class from the others. More field acquired GPS training data will also improve the model's accuracy.

Conclusions

The *Phragmatis* covers around 9.5% of the total area, and *Bullrush* covers around 2.8% of the area. The Overall Mapping Accuracy was of 67.52%. *Bullrush* grass had the highest mapping accuracy: 78%, followed by *Phragmatis* with 74%. Open water had the lowest mapping accuracy: 54%

Our data indicate that Landsat imagery and remote sensing tool promise to potentially describe and predict spatial and temporal changes in macrophytes vegetation in Utah Lake.

According to the obtained results, we stayed with the use of Landsat imagery and the proposed procedure for a multitemporal analysis of macrophyte distribution in Utah Lake. This represents a quick and affordable method. The use of a higher resolution sensor such as 15-m resolution Aster imagery or aerial photographs with a more intense field work can produce a finer result, but a higher cost, so the chance of replicability through time is reduced.

More GPS-ground data may be needed to improve the Overall Mapping Accuracy. As it was mentioned before, there is a potential to use high resolution sensors, however there are some restriction regarding its replicability. High resolution imagery is expensive and Landsat imagery still offers an affordable availability of images. The use of Landsat imagery seems to be a promising tool for past and future monitoring of macrophytes taxa and distribution in Utah Lake

This study demonstrates the effective use of GIS and remote sensing tool promise to describe and predict potentially spatial changes in macrophytes vegetation at the lake ecosystem level. Older modeling prediction techniques provided little spatial information of where plant species distribution could be expected to be located in lake ecosystems.

GIS and Remote Sensing techniques combined with statistical analyzes, offer a promising tool to place plant distributions along environmental gradients, and thus providing important knowledge of where management efforts might be efficiently directed to mitigate the negative aspects of such possible vegetation change.

Acknowledgements

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