Journal of Arid Environments 102 (2014) 68–75

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Modeling meadow distribution for conservation action in arid and semi-arid Patagonia, Argentina

Ramiro D. Crego [a,b,*], Karl A. Didier [c], Clayton K. Nielsen [a,b,d]

[a] Cooperative Wildlife Research Laboratory, 1125 Lincoln Drive, 251 Life Science II, Southern Illinois University, Carbondale, IL 62901-6504, USA
[b] Department of Forestry, 1205 Lincoln Drive, 184 Agriculture Building, Southern Illinois University, Carbondale, IL 62901-6504, USA
[c] Wildlife Conservation Society, 2300 Southern Boulevard, Bronx, NY 10460, USA
[d] Center for Ecology, 1125 Lincoln Drive, 326 Life Science II, Southern Illinois University, Carbondale, IL 62901-6504, USA

ARTICLE INFO

Article history:
Received 14 September 2012
Received in revised form
14 December 2012
Accepted 27 November 2013
Available online 18 December 2013

Keywords:
BIOMOD
Ensemble techniques
Mallines
Species distribution models
Wetlands

ABSTRACT

Meadows are critical in arid and semi-arid Patagonia because of their importance for regional biodiversity. Despite this, little information on the spatial distribution of meadows is available, which hampers conservation planning. We modeled the spatial distribution of meadows across arid and semi-arid Patagonia, Argentina, and investigated conservation status of those areas predicted to contain meadows. We used high-resolution imagery available in Google Earth Software to visually estimate presence and absence of meadows. We used these observations and 11 socio-environmental predictor variables to model the distribution of meadows using generalized linear, additive, boosting, and random forest models, as the basis for a final mean ensemble technique. The final ensemble model improved accuracy over any of the single models, with an accuracy (area under the curve of the receiver-operating characteristic plot) of 0.97. Based on the final ensemble model, only 0.14% of predicted meadows occur inside current International Union for Conservation of Nature level I, II or III protected areas. Our final ensemble model was an accurate representation of the distribution of meadows in Patagonia and indicates they are severely under-represented within protected areas. This first regional map of meadow distribution across Argentinean Patagonia represents key information for planning actions to conserve this critical habitat.

1. Introduction

Wetlands include a variety of temperate freshwater systems distributed in major ecoregions of the world (Brinson and Malvárez, 2002) and are imperative for providing critical habitat for many species (Bedford et al., 2001). Although wetlands encompass a small portion of arid and semi-arid landscapes, they drive many ecosystem processes, such as weathering, soil formation, biological activity, and nutrient pools (Newman et al., 2006). Worldwide, wetlands are strongly and negatively influenced by anthropogenic activities, because societies commonly settle where wetland areas occur (Brinson and Malvárez, 2002).

In Argentina, wetlands make up approximately 5% of arid and semi-arid Patagonia (Iriondo, 1989), including lakes, ponds, peatlands (turberas), and meadows (mallines; Brinson and Malvárez, 2002). Meadows are grasslands located in low areas, valley rivers, or at sides of hills and are continually irrigated with superficial and underground water (Mazzoni and Vázquez, 2004). Consequently, meadows can be small isolated patches on hillsides or form large continuous areas following the drainage system along valleys. Although vegetative composition of meadows is internally heterogeneous depending on flooding intensity and duration, generally a gradient from the stream to the periphery can be differentiated: a central area of high moisture dominated by hydrophilic species and a periphery dominated by mesic species that at the border becomes closer in vegetative composition to the surrounding steppes (Boelke, 1957). Even though meadows encompass a small portion of Patagonia, they are important systems in the arid landscape. Vegetation found in meadows present rates of primary production three to five times higher than the surrounding steppe (Irisarri et al., 2012), which together with the permanent source of water, creates important resources and habitat for native terrestrial species. These grasslands are highly used by guanacos (*Lama guanicoe*), the largest herbivore of Patagonia (Ortega and Franklin, 1988), and by several bird species that use them for feeding, reproduction, and resting (Mazzoni, 2000).

* Corresponding author. Cooperative Wildlife Research Laboratory, Department of Forestry, 1125 Lincoln Drive, 251 Life Science II, Southern Illinois University, Carbondale, IL 62901-6504, USA. Tel.: +1 618 453 6947; fax: +1 618 453 6944.
E-mail addresses: ramirocrego84@gmail.com (R.D. Crego), kdidier@wcs.org (K. A. Didier), kezo92@siu.edu (C.K. Nielsen).

0140-1963/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jaridenv.2013.11.008

Furthermore, many studies suggest the importance of meadows for regional biodiversity in general (Brinson and Malvárez, 2002; Perotti et al., 2005). Nevertheless, because meadows are highly productive and provide permanent access to water, they are prime locations for anthropogenic development. As a consequence, meadows are threatened in Patagonia, with water erosion and overgrazing by livestock the major cause of degradation (Paruelo and Aguiar, 2003; Perotti et al., 2005).

Several studies have been conducted in Patagonia across relatively small areas (i.e., 10,000–85,000 km^2) where meadows were mapped using remote sensing techniques with Landsat TM images (Ayesa et al., 1999; Bran et al., 1998; Mazzoni and Vázquez, 2004; Paruelo et al., 2004). Because meadows are rare on the landscape, a common technique for mapping their distribution is to use moderate to high resolution satellite imagery (i.e., Landsat TM, 30 m spatial resolution) with an image classification process. Unfortunately, it would be nearly impossible to compile a set of cloud-free images from the same time period to perform a classification analysis over a large study region such as ours (i.e., a mosaic of about 52 Landsat TM images would be necessary to cover Patagonia). However, the recent improvement of Geographic Information Systems (GIS) together with powerful statistical tools has led to development of predictive species distributions models (SDMs), which make it possible to map the broad scale distribution of biological entities and consequently improve management decisions and conservation strategies (see Peterson, 2006). Species distribution models are empirical models that relate species occurrence data with environmental predictor variables such as climate, geology, and topography (Guisan and Thuiller, 2005; Guisan and Zimmermann, 2000). Such modeling techniques have been used broadly to model distributions of individual species, but also entire communities such as grasslands, thereby producing information on spatial patterns in distribution of biodiversity (Ferrier and Guisan, 2006).

Much of Patagonia is altogether unprotected from anthropogenic degradation, thus making meadows even more vulnerable to degradation. Only 4.7% of arid and semi-arid Patagonia is protected and <1% is protected by the International Union for Conservation of Nature (IUCN) level I, II, or III reserves (Burkart et al., 2007). Furthermore, the extent of meadow protection is entirely unknown. In Patagonia, a current and broader-scale study is necessary to truly assess meadows distribution. Given the significance of meadows to regional biodiversity, a current distribution model would be an important data layer to include in future conservation planning projects, and could be also used as a surrogate to account for endemic or restricted range species associated with this environment (Ferrier, 2002). In this study we used an SDM approach within the platform BIOMOD (Thuiller et al., 2009) to model the current distribution of meadows in arid and semi-arid Patagonia. We used four modeling techniques, generalized linear models (GLM), generalized additive models (GAM), general boosting models (GBM), and random forests (RF), to generate individual predictive distributions. We then used these predictive distributions as the basis of a mean ensemble method (Marmion et al., 2009) to create our final model. The main aims of this study were to (i) generate a final ensemble distribution model of the distribution of meadows in arid and semi-arid Patagonia; and (ii) investigate conservation status of those areas predicted to contain meadows.

2. Materials and methods

2.1. Study area

Arid and semi-arid Patagonia (excluding the subantartic andino-patagonic forest strip and the seacoast) is >700,000 km^2 in area and extends from 39° to 55° S and from the Atlantic Ocean to the Andean piedmont in the west. This study area includes two major phytogeographic provinces: Patagonia, a mixed of grass-shrub steppes and semideserts in central and southern Patagonia, and the Monte, composed by shrub steppes in northern Patagonia (León et al., 1998). The climate of the area is cold-temperate. The mean annual temperature ranges from 12 °C in the north to 3 °C in the south, with absolute minimum temperatures below −20 °C (Paruelo et al., 1998). From the Andes to the coast, annual precipitation decreases considerably, with a mean annual precipitation for central Patagonia of 200 mm per year (Paruelo et al., 1998).

2.2. Presence/absence data for model calibration

Meadows present high spectral contrast with respect to the surrounding steppe, thus they can be easily distinguished from surrounding land cover if satellite imagery is sufficiently high in spatial resolution. During December 2011–January 2012 we used high-spatial-resolution imagery (<4 m) compiled in the Google Earth database (version 6.1, Google Inc., Mountain View, CA, USA) to identify presence of meadows across the study area. Google Earth is one among many Virtual Globe software systems that are being used with growing frequency in many research fields (Sheppard and Cizek, 2009). The Google Earth model of the world consists of hundreds of thousands of satellite and aerial images combined from different sources, including non-commercial satellites (e.g., Landsat, Spot) and commercial satellites (e.g., Digital Globe's QuickBird) and also many providers of aerial photographs. For this reason, we could not determine the year of each image used for assessing meadows presence; however, Google Earth ensures the best image available, which typically included images 1–3 years old (Google Corporation, 2012).

We assessed the presence or absence of meadows across the study area by overlaying it with a grid of 1 km^2 cells and visually assessed a sample of those cells for meadows. We knew *a priori* that they occurred in a small portion of the study region (approximately 5%) and were more likely to be abundant in river valleys and closer to the Andes Mountains. To ensure that our training/validation data set had a sufficient number of presences, we used an equal-stratified sampling strategy; this design ensures more accurate model predictions than the proportional-stratified design (Hirzel and Guisan, 2002). We stratified the study area based on elevation (east-west gradient) and distance from rivers given their known influence on potential meadow locations (Bran et al., 1998). We defined three strata for elevation (stratum 1: 0–400 m; stratum 2: 401–800 m; stratum 3: >801 m) and two strata for distance from rivers (stratum 1: 0–2000 m; stratum 2: >2001 m). From the study area grid, we randomly selected 167 cells per stratum (1002 cells in total) using the NOAA's Biogeography Branch Sampling Design Tool for ArcGIS (http://ccma.nos.noaa.gov/products/biogeography/sampling/, accessed 13 Nov 2011). In total, we randomly selected 1002 cells, aiming to ensure >100 presences.

High resolution imageries provided by Google Earth make it possible to differentiate meadows, which appear visually as continuous patches of different shades of green, from the surrounding gray and brown steppe. To determine if a meadow was present (1) or absent (0) in a particular 1 km^2 cell, we first examined the quality of Google Earth imagery within the 1002 cells chosen for sampling. Only cells completely covered by high resolution imagery were kept; others were discarded if covered by snow or clouds or unclear. If the cell was covered by ≥5% of meadows, we considered meadows to be present, otherwise, we considered that meadows were absent.

We were concerned that our ability to detect meadows when present may be imperfect and, further, that detection ability may